TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
PROJECT PLANNING BRANCH

THE
DUCK RIVER
PROJECT

Normandy & Columbia Reservoirs

PLANNING REPORT NO. 65—100-1

KNOXVILLE, TENNESSEE
SEPTEMBER 1968

THE DUCK RIVER PROJECT

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SUMMARY

SUMMARY

This report summarizes the findings of a comprehensive engineering study of the development potential of the main stem of the upper Duck River. It presents a plan for a multiple-purpose water control system which consists of dams at the Normandy and Columbia sites. The estimated cost of construction of the Duck River project is $73,500,000.

The proposed system would aid in the economic advancement of the upper Duck River region. It would provide flood relief in urban and agricultural areas; would improve the quality and quantity of water available for municipal and industrial use; would create opportunities for development of the recreation potential, including fishing and hunting, in and around the reservoirs; would result in improved highway travel in the project area; and would enhance the value of land along the shoreline. The project also would provide redevelopment and expansion benefits from more productive employment of the local labor force.

Normandy Dam would be located at mile 248.6 on the Duck River in Coffee and Bedford Counties, about 8 miles north of Tullahoma, Tennessee. The dam would be a rolled earth-fill embankment with maximum height of 110 feet and 2,800 feet long, including the spillway. The drainage area at the site is 195 square miles. The reservoir, at normal maximum pool, elevation 875, would cover an area of 3,200 acres, mostly in Coffee County, extending upstream about 17 miles.

Columbia Dam would be located in Maury County at Duck River mile 136.9, about 4 river miles upstream from the city of Columbia, Tennessee. It would be a rolled earth-fill embankment having a maximum height of 105 feet and a length of 2,325 feet, including the spillway. The drainage area at the site is 1,181 square miles. At normal maximum pool, elevation 630, the reservoir would cover an area of 12,600 acres in Maury and Marshall Counties, extending more than 54 miles upstream.

The two reservoirs would provide about 340,000 acre-feet of detention capacity for flood control. Floods equal to the flood of record and greater floods having a frequency of occurrence of approximately 300 years would be reduced to essentially nondamaging stages in the vicinity of Columbia, Tennessee. The

project would also provide flood relief at Shelbyville and Centerville. Flood damages on almost 10,000 acres of agricultural land downstream from the dams and to roads and bridges in the area would be significantly reduced. The reservoir storages also would assist in controlling floods along the Tennessee River downstream from Kentucky Dam and along the lower Ohio and Mississippi Rivers. The total annual value of the flood control benefit is estimated to be $365,000.

The project would furnish a reliable source of water supply for present and future municipal and industrial requirements in the four counties of the upper Duck River Basin--Maury, Marshall, Bedford, and Coffee. The raw-water supply for the water grid system planned in these counties would be improved, although the most significant benefit would accrue to the downstream industrial complex in Maury County. The annual value of the water supply benefit is estimated to be $810,000.

Even if the municipal and industrial waterborne wastes originating in the Shelbyville and Columbia, Tennessee, areas were given both primary and secondary treatment, the unregulated flow in the Duck River would not be sufficient to maintain acceptable water quality at times of low flows. Storage releases, primarily from Normandy Reservoir, would supplement streamflow so that the residual load would not exceed the assimilative capacity of the river. The annual benefit from the project attributable to the augmentation of low flows is estimated to be $365,000.

The reservoirs would provide an excellent opportunity for a variety of water-oriented activities, together with other types of recreation opportunities now deficient in the watershed. They would be readily accessible from several regional population centers and would be only a day's travel time from metropolitan areas of the Midwest, by interstate routes. It is estimated that the reservoirs would receive 1,065,000 annual recreation visits after 5 years, increasing to 1,470,000 by 2020, excluding those visits made primarily for hunting and fishing and the visits made solely to the dam site areas. The average annual value of the recreation visitation is estimated to be $1,275,000. The possibility of a scenic stream development downstream from Normandy Dam is being evaluated to determine its relationship to the overall project.

Both reservoirs would offer attractive boat and bank fishing, and reaches of the river immediately downstream from the dam sites could also be developed for fishing. In addition, a subimpoundment is planned for the Cedar Creek embayment of the Columbia Reservoir which would provide a constant-level lake and a waterfowl refuge and hunting area. The impoundment would be managed primarily for goose hunting but also would have added benefits from managed fishing. The estimated annual value of the hunting and fishing benefit for the project is $200,000.

Approximately 18,000 acres of land around the two reservoirs would be acquired in order to prevent unreasonable severance damage, avoid undue expense in providing access to isolated tracts, and ensure maximum development and use of the reservoirs for purposes of public benefit. The project would enhance the value of a large portion of this land. Some 9,000 acres of the acquired land, not reserved for recreation or wildlife purposes, and an additional 1,500 acres of adjoining land remaining in private ownership would produce shoreline development benefits having an annual value of $370,000.

The relocation of highways in the reservoir areas would result in improvement in grade and/or alignment of many of the existing travel routes. This transportation savings benefit has an average annual value estimated at $50,000.

Construction, operation, and maintenance of the Duck River project would provide employment to some of the otherwise subemployed labor in the area. This redevelopment benefit from the more productive use of labor is estimated to have an equivalent annual value of $80,000.

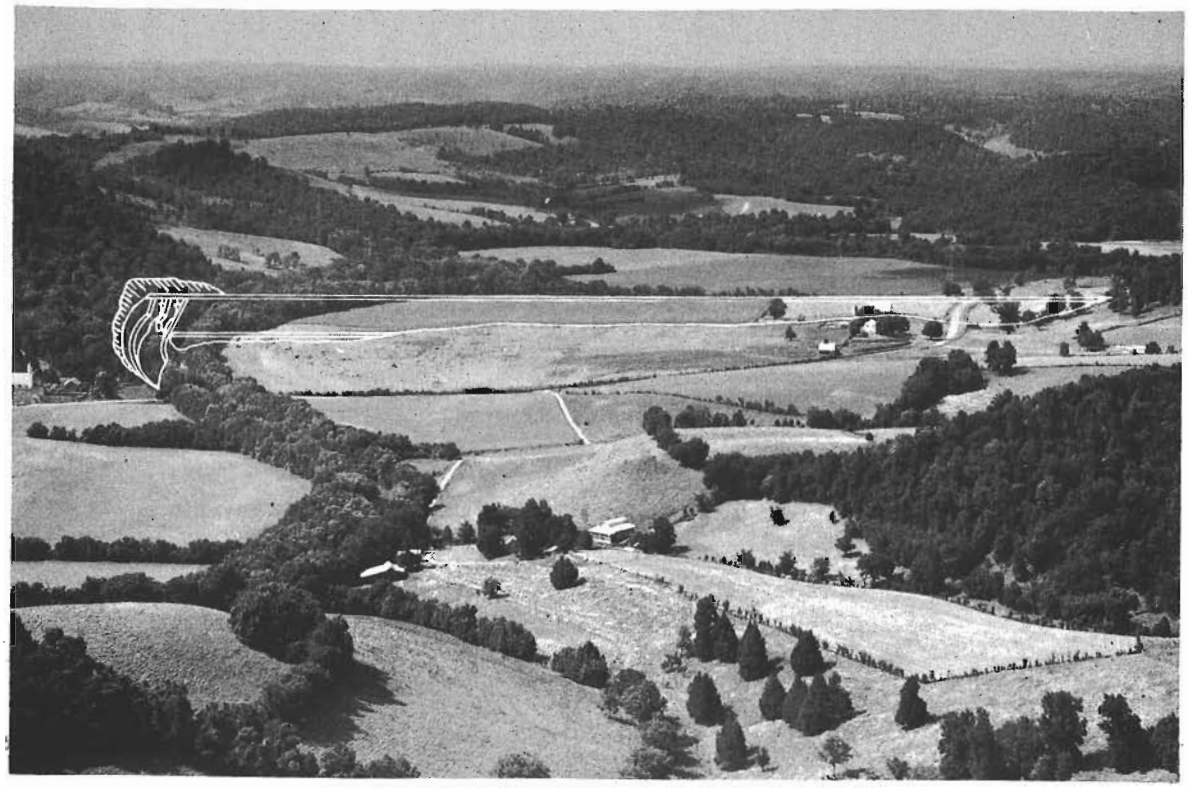
A larger and longer lasting benefit from more productive use of subemployed labor would be provided by the creation of more jobs in industrial and related trades and services employment. The industrial growth would occur on sites located downstream from the dams, which would be benefited primarily by an assured water supply of high quality and by increased flood protection. Analyses indicate that after the project is built, high-wage industries with an employment of about 3,000 and an annual payroll of more than $22,000,000 (1966 wage level) could be expected to locate on these waterfront sites. An equal number of trades and services jobs would follow from the

increased industrial employment and would have a payroll approaching $15,000,000. The estimated expansion benefit from more productive use of the subemployed in these new jobs has an annual equivalent value of $1,445,000 after (1) limiting the benefit to the first 25 years of project life, (2) discounting for lag in accrual, and (3) crediting the project with only that part of the benefit equal to its share of the public investments considered necessary to accommodate the industries.

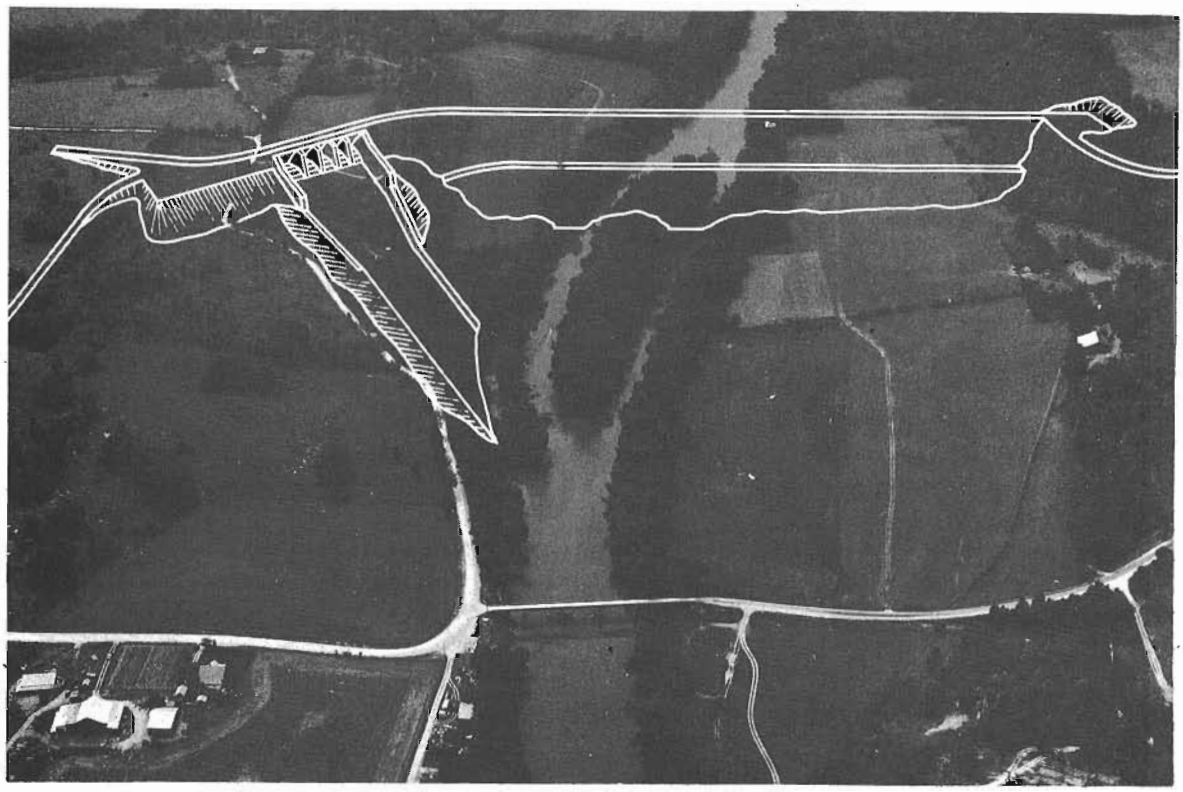
The total annual benefit resulting from construction of the Duck River project would amount to $4,960,000 and the annual cost, including the estimated operation and maintenance costs and an allowance for interest during construction, would be $4,050,000. Interest and amortization have been computed at 4-5/8 percent. The project is assumed to have a 100-year economic life. The benefit-cost ratio for the project is 1.2 to 1.0.

A supporting report entitled "The Potential Impact of Water Quality of the Duck River Project" describes in detail the water quality aspects of the project. The relationship of the water resource development to the overall upper Duck River development program is presented in a companion report, "The Upper Duck River Development - A Cooperative Plan for Economic Growth." Project planning report No. 65-100, "The Columbia Project on the Duck River," issued in August 1967, is superseded by this report.

REPORT



The Normandy Dam Site



The Columbia Dam Site

THE DUCK RIVER PROJECT

REPORT

In 1964 the people of Coffee, Bedford, Marshall, and Maury Counties, Tennessee, organized the Upper Duck River Development Association and requested assistance from TVA in organizing a program for tributary area development. The first step in the program was an inventory of the area's resources to identify its needs and opportunities. This step was completed in July 1965; and the results of the inventory were published in a report entitled "Upper Duck River Valley, Summary of Resources."

Early in 1965, in response to requests from officials in the Upper Duck River Development Association, the Tennessee Upper Duck River Development Agency was created by the Tennessee State Legislature as a "public body corporate and politic" to develop and effectuate "plans and programs for comprehensive development including the control and development of the water resources," with the legal authority necessary to carry out certain phases of a resource development program. In order to coordinate the activities of the three groups principally concerned with resource development in the area, a memorandum of understanding among TVA, the Upper Duck River Development Association, and the Tennessee Upper Duck River Development Agency was agreed to in August 1966.

The Upper Duck River Regional Planning Commission was created in May 1966 at the request of the cities and counties within the area. This organization is responsible for planning comprehensive developmental activities in cooperation with the city and county planning commissions and the Tennessee State Planning Commission.

The inventory of resources showed that the Duck River must be controlled if the water resources of the area are to be fully utilized in promoting the economic growth of the region. The river has extreme variations in the amount of streamflow, ranging from frequent flooding in the winter months to poorly sustained flows during the late summer and fall. Heavy rains in the December-through-March period often swell the streams above flood stage,

causing damages to urban and agricultural lands and seriously affecting highway travel within the region. On the other hand, during August, September, and October a substantial number of small and moderate-size streams cease to flow. These periods of low flow are as great a disadvantage to the economic development of the area as is the flooding. Certainly, water in ample quantity and of good quality is essential to assure the overall economic growth.

This report presents a multiple-purpose plan for the Duck River project, which would utilize more fully the water resources potential of the Upper Duck River Basin. The plan consists of the Normandy and Columbia Dam and Reservoir units. The project would provide benefits from flood control, water supply, water quality control, recreation, fish and wildlife, improved highway travel, and development of land adjoining the reservoirs for purposes of public benefit. It also would provide more productive employment of the local labor force in direct project employment and in project-induced, higher wage jobs associated with industrial and related trades and services employment.

THE BASIN

The part of the drainage area lying in the Upper Duck River Basin is that portion upstream from mile 98 which encompasses an area of about 1700 square miles, located in middle Tennessee (see exhibits 1 and 2). It includes most of Coffee, Bedford, Marshall, and Maury Counties, extends some 75 miles in an east-west direction, and has an average width of about 25 miles. The river itself divides the upper basin almost in half as it follows a 190-mile-long, meandering course from the headwaters, above Manchester, to the western boundary at the Maury-Hickman County line. The stream flows from the eastern Highland Rim plateau, in Coffee County, across Bedford, Marshall, and Maury Counties, which lie within the Nashville Basin--one of the richest agricultural regions in the state--and then through the western Highland Rim in the lower Duck River Basin, and on into Kentucky Lake at Tennessee River mile 110.7. It descends from the plateau to the basin at an average fall of about 8 feet per mile in the 23-mile reach between the communities of Manchester and Normandy. Downstream from Normandy the fall averages about 2 feet per mile in the 150 miles across the Nashville Basin to the Maury-Hickman County

line. The major tributaries of the upper Duck River, all located within the Nashville Basin, and their drainage areas are as follows:

Stream	Mouth, at Duck River Mile	Drainage Area, Square Miles
Big Bigby Creek	109.2	129
Little Bigby Creek	127.9	46
Rutherford Creek	130.4	116
Fountain Creek	145.9	103
Flat Creek	166.6	51
Big Rock Creek	180.4	121
North Fork Creek	191.9	78
Flat Creek	219.1	50
Garrison Fork	239.5	130

Several smaller tributaries upstream from the Normandy Dam site, in the Highland Rim Province, and their drainage areas are as follows:

Stream	Mouth, at Duck River Mile	Drainage Area, Square Miles
Riley Creek	250.9	11
Carroll Creek	253.6	22
Crumpton Creek	258.4	31
Little Duck River	268.6	43.5

The Highland Rim plateau in the upper portion of the watershed consists of a very level and submaturely dissected peneplain standing at about elevation 1000. This plateau completely encircles the Nashville Basin with a fairly definite, though ragged, escarpment; and outliers from it extend far into the basin, appearing in the form of spurs and isolated hills that rise 200 to 300 feet above the surface. The basin consists mainly of a rolling, hilly area with a surface at about 600 to 700 feet above sea level, having much more local relief than the Eastern Highland Rim. The lower portion of the watershed, outside the area under study, lies in the Western Highland Rim where mature dissection has left relatively high ridges and hills. There are several caves in the area, as well as a number of waterfalls, especially in the vicinity of the river near Manchester.

About 60 percent of the basin is in farm land. The forest area, which makes up the rest of the area, is characterized by small scattered woodlands, mostly in farm ownership. The eastern portion of the basin in Coffee County is most heavily forested.

Transportation

The important highway and rail routes through the area fan out from Nashville in a southerly direction. These routes not only serve to connect the four urban centers in the Duck River area with Nashville and other points within the state but are also the main arteries from Chicago and the Midwest to Florida and the Gulf Coast. Travel within the four counties is facilitated by a number of state highways that serve as connector routes. The transportation network in the basin is shown on exhibit 2. Exhibits 10 and 11 show in more detail the routes within the Normandy and Columbia Reservoir areas respectively.

Major highway access into the region is provided by seven Federal primary routes and two state routes. In addition, Interstate 65 is a major north-south route from Chicago to Mobile and Interstate 24, now under construction across Coffee County, will be a connector route from Chattanooga through Nashville to its terminus near Cairo, Illinois (see figures 1 and 2). East-west travel through the basin would be greatly improved by the construction of a proposed highway that will follow generally along State Routes 50, 64, and 55, running from Interstate 40 near Only, in Hickman County, Tennessee, to the Appalachian corridor at Sparta, Tennessee.

Railroad service to the basin is furnished through three main lines of the Louisville and Nashville Railroad Company. One runs through Tullahoma and has branch lines connecting with Shelbyville and Manchester; the second runs through Columbia between Birmingham and Nashville; and the third, a parallel line from just south of Nashville to Athens, Alabama, passes through Lewisburg. The first line could serve potential industrial sites in the Normandy Reservoir area and downstream to Shelbyville, and the second two could serve sites in the Columbia Reservoir area.

Southern Airways provides service to the Shelbyville-Tullahoma area at Bomar Field, located north of Shelbyville.

Figure 1 - Interstate Highway 65, Looking North

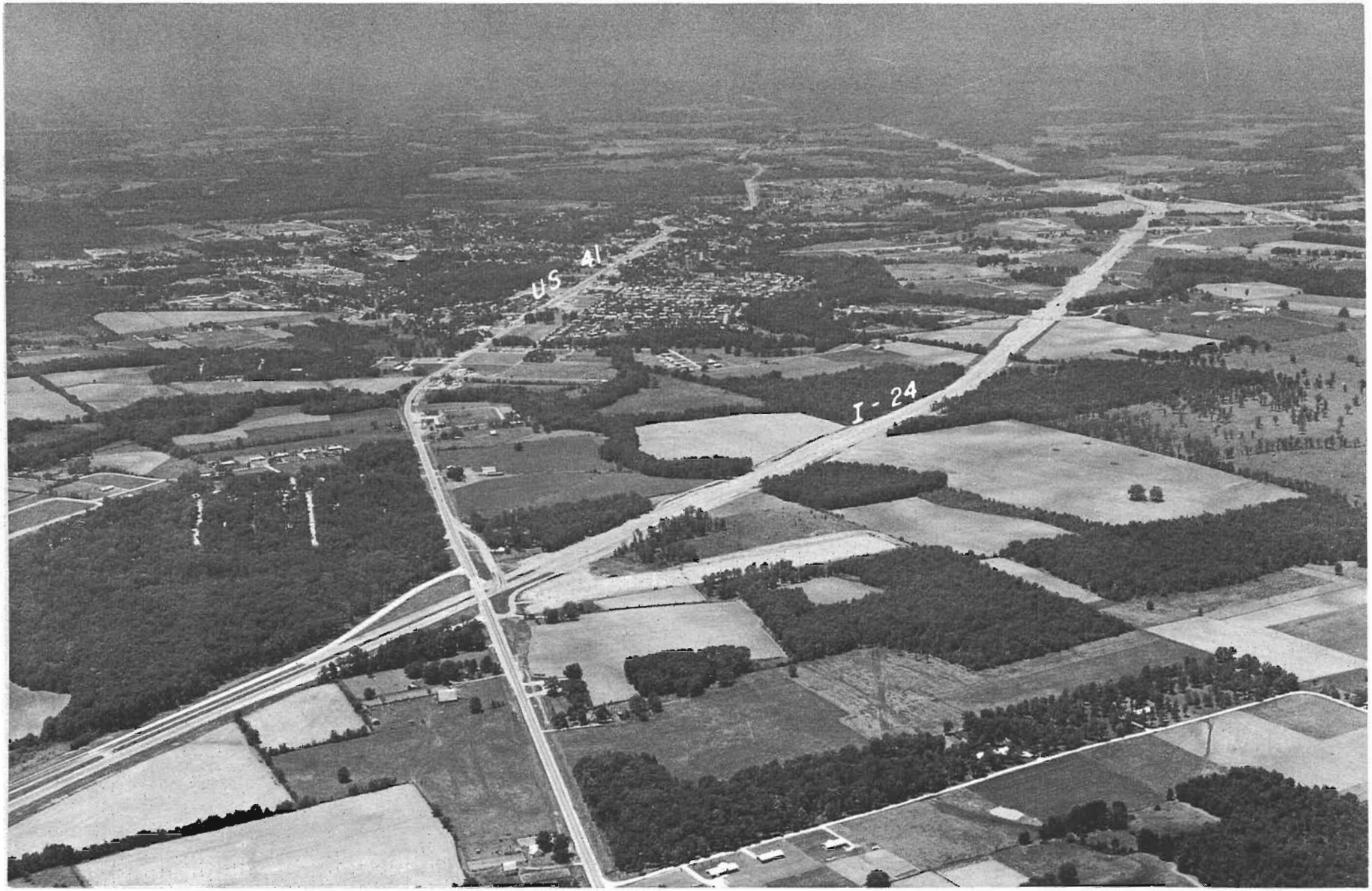


Figure 2 - Aerial View of Intersection, Interstate Highway 24 and U. S. Highway 41

Water Grid System

Plans for a water grid system have been made by the five major cities in the upper Duck River Basin to interconnect their systems for greater economy, to aid industries requiring treated water, and to supply water to rural areas of the four counties. Federal grants, supplemented by municipal bonds, have been obtained for the first phase of the grid system, and construction is nearing completion. The system shown on exhibit 9 does not necessarily represent actual water lines but rather the present concept of feeder mains radiating out from the cities. The water mains will form a network for an ultimate system to serve the entire 4-county area.

Four of the five cities in the water grid system--Manchester, Shelbyville, Lewisburg, and Columbia--obtain most of their raw-water supply from the Duck River. The latter three cities have their water pumping stations located on small impoundments of the Duck River which provide cover for the intakes but do not have any significant storage. The fifth city, Tullahoma, utilizes a system of springs in the headwaters of the Duck River but will require a new source in the near future from either the Duck or Elk Rivers. Aerial photographs of the five cities are shown in figures 3 through 7.

Normandy Reservoir would help to assure an adequate supply of water for the future needs in Coffee and Bedford Counties. The construction and operation of the water grid system in Coffee County will be divided between the cities of Manchester and Tullahoma. These cities will have to relocate their individual pumping stations on the reservoir or consider combining their facilities for a more efficient operation of the system if they are to meet the future needs of the area. In Bedford County the city of Shelbyville is well situated to supply the needs of the water grid system. Expansion of the present pumping station should take care of the city and county for future years.

Maury and Marshall Counties would be assured of an adequate water supply from Columbia Reservoir. The city of Columbia would construct and operate the water grid system in Maury County. The city's present pumping station, located on the Duck River within the city limits, could be expanded to utilize releases from Columbia Reservoir; or provision could be made to take

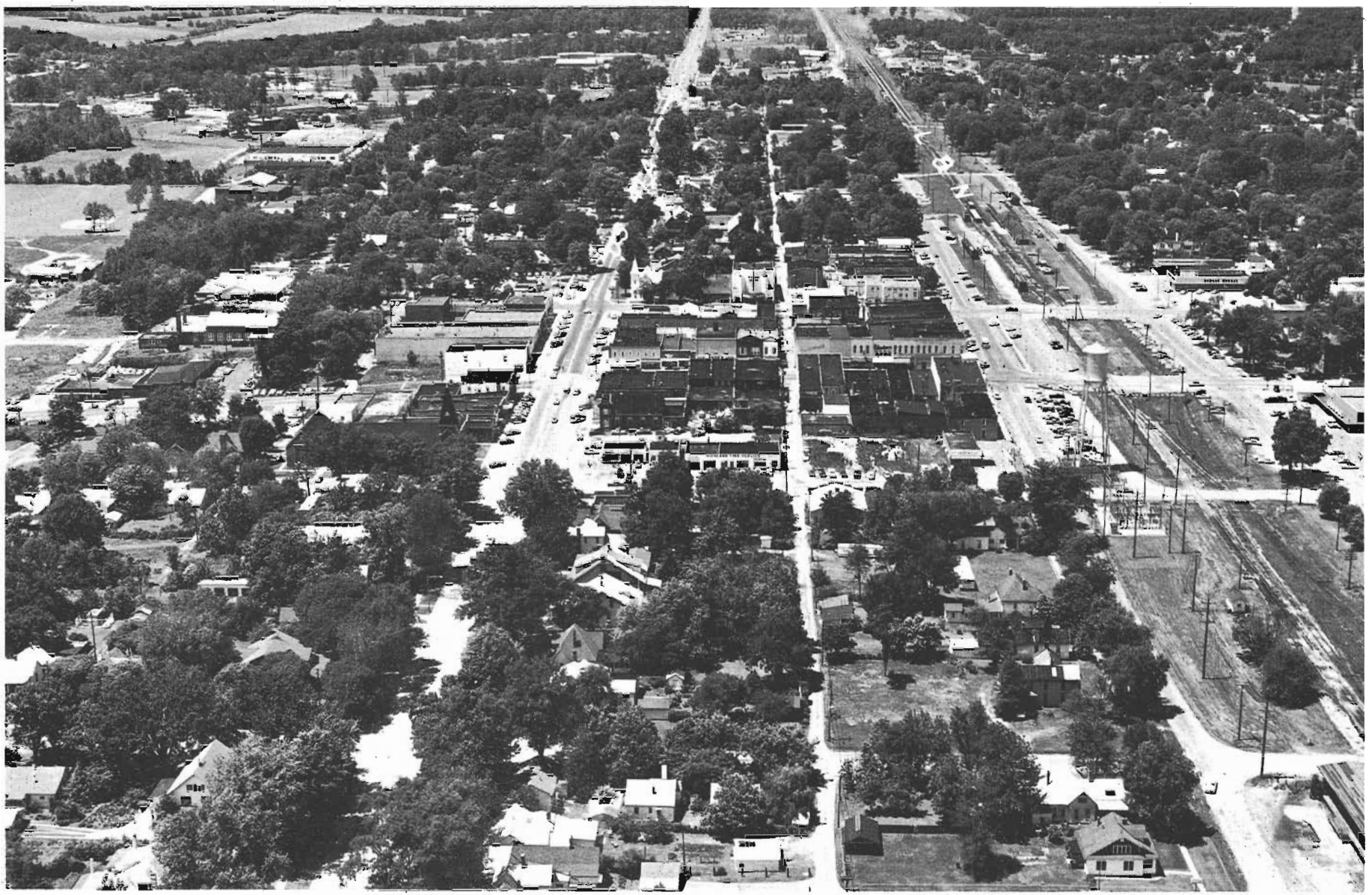


Figure 3 - Tullahoma, Tennessee

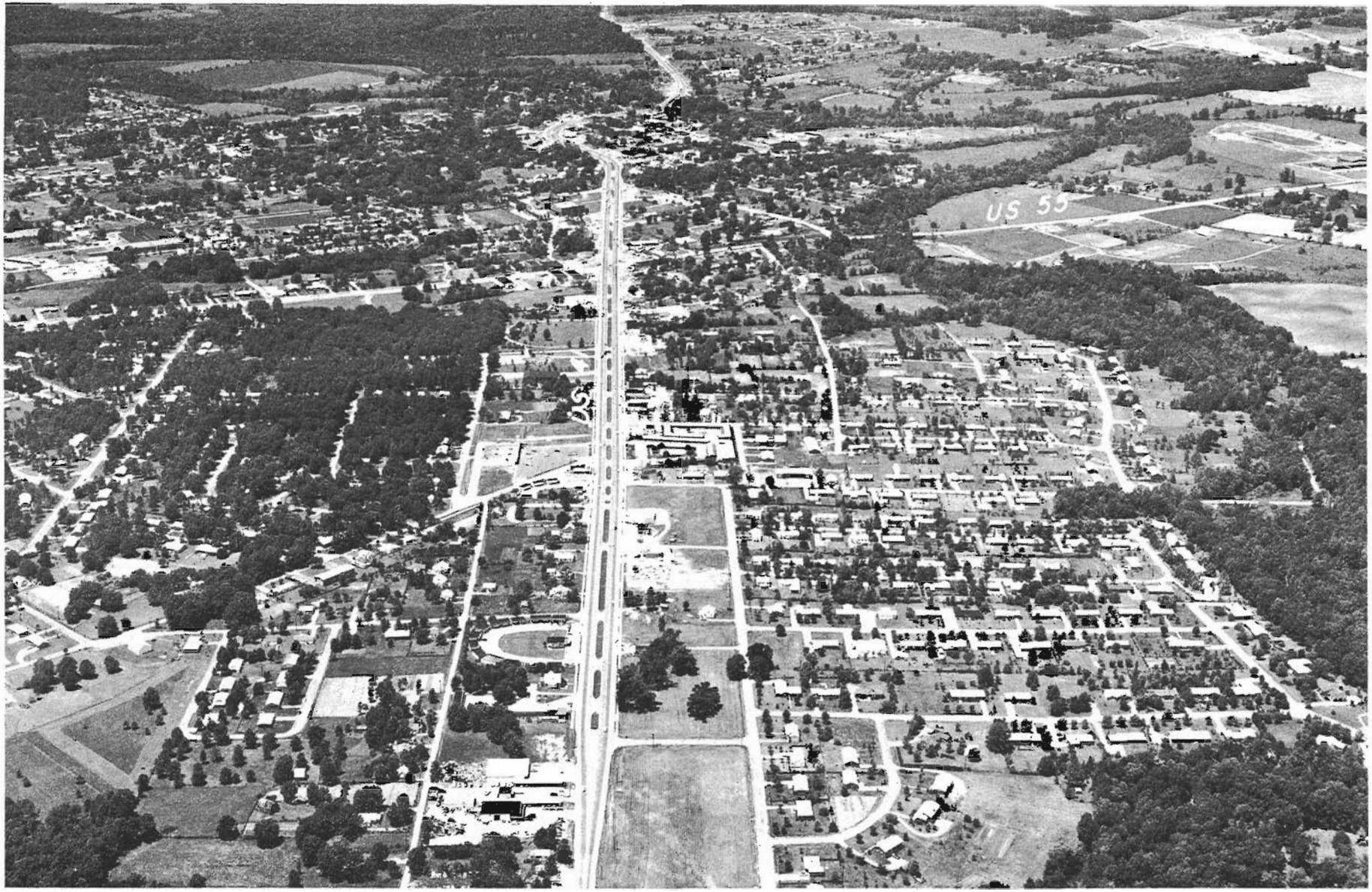


Figure 4 - Manchester, Tennessee

Figure 5 - Shelbyville, Tennessee

Figure 6 - Lewisburg, Tennessee, Looking North

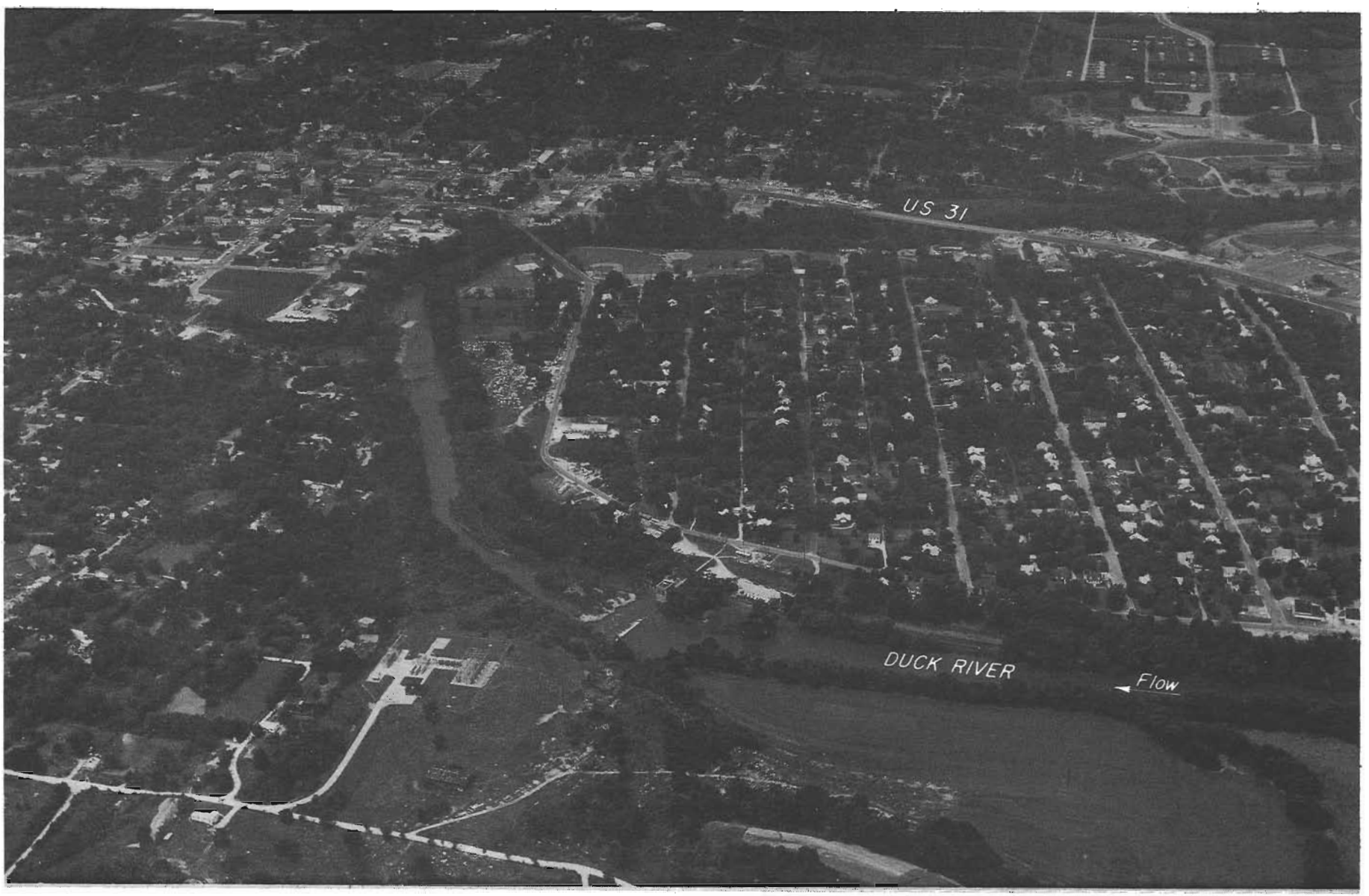


Figure 7 - City of Columbia, Tennessee, Looking Northwest

water directly from the reservoir. Either would adequately serve the city and county for future years. In Marshall County, the Lewisburg water system would be expanded to serve the water grid. The pumping station for Lewisburg is located on the Duck River at mile 181 upstream from Lillard Mill Dam. The pumping head would be decreased when the Columbia Reservoir is above elevation 620. Lillard Mill Dam, with crest at about elevation 620, would be retained to provide cover for the intake during the winter months when the reservoir level would be drawn for flood control.

HYDROLOGY

Rainfall

The average annual rainfall over the upper Duck River watershed for the 30-year period 1935 through 1964 was 52 inches. During this period the driest year was 1941 when the rainfall totaled only 37 inches. The wettest year was 1950 when 65 inches was recorded, of which more than 16 inches fell in January. January is usually the wettest month, with more than twice the rainfall on the average as October, the driest month. The watershed has about 50 days of agricultural drought in the average year. The average rainfall during the growing season, from April through September, was 24 inches during the 30 year period.

Streamflow

Records of streamflow of the upper Duck River are available at the following gages for the years shown:

Stream Gage	Drainage Area, Square Miles	Period of Record
Below Manchester	107	1934 to date
At Normandy	208	1921 to 1931
Near Shelbyville	481	1933 to date
At Columbia	1208	1904-1908; 1920 to date

Pertinent data at these stations follow:

Stream Gage	Discharges				Avg Annual Discharge, CFS
	Maximum		Minimum		
	Date	CFS	Date	CFS	
Below Manchester	Mar 1929	50,000	Aug 1934	8	176
At Normandy	Mar 1929	60,000	Not available		370
Near Shelbyville	Mar 1902	87,000	Aug 1936	5	790
At Columbia	Feb 1948	61,000	Oct 1922	0	1913

Based on the records at these gaging stations, the average annual runoff at the Normandy and Columbia Dam sites is 320 cfs and 1870 cfs respectively. This flow is equivalent to about 1.6 cfs per square mile, or 22 inches per year on the respective drainage areas. Average annual runoff, therefore, is about 42 percent of the average annual rainfall. A large part of the volume of streamflow in the Duck River watershed occurs in the first quarter of the year. The flow decreases after March to a minimum, usually in September or October. Streamflow in the Nashville Basin portion of the watershed becomes very low during dry periods and some of the smaller streams cease to flow. In fact, a U. S. Geological Survey team making a series of discharge measurements along the Duck River between Shelbyville and Columbia on September 25, 1949, found that of the 19 tributaries in the reach 13 were dry and the combined flow of the other 6 was only 5.2 cfs. Low-flow measurements were made on nearly all streams in the watershed by the USGS during October 1953. These records showed there was no contribution to the Duck River from the tributaries between Shelbyville and Columbia. During such low-flow periods normal evapotranspiration losses in this 83-mile reach may result in a reduction in streamflow of up to 15 cfs.

Floods

The Duck River Basin lies approximately normal to the path of heavy winter storms which move northeastward across the Tennessee Valley. The USGS has operated a recording stream gaging station on the Duck River at mile 216.15, near Sims Bridge and 5 miles below Shelbyville, since April 1934.[1]

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1. Report No. 0-5480, "Floods on Duck River in Vicinity of Shelbyville, Tennessee." Division of Water Control Planning (May 1957).

Records of gage heights on the Duck River at Columbia extend back to 1887. Gage records were kept at Normandy from December 1920 through March 1931, which were useful in estimating flood heights at Shelbyville prior to 1934.

The table on page 16 lists stages, elevations, and discharges for flood crests exceeding bankful elevation 705.5 at the gage near Shelbyville. It includes dates and estimated gage heights for a number of floods occurring prior to establishment of the gaging station in 1934. Discharges are estimated only for the more important floods in this period. The heights of flood crests for the prerecord floods of March 1902, December 1926, March 1929, and March 1934 were determined from high-water profiles for those floods. The heights for other prerecord floods listed in the table were approximated by correlation with gage records at Columbia, downstream from Shelbyville, and at Normandy, upstream from Shelbyville. No gage height data are available for the floods listed prior to 1887.

The flood of record at Shelbyville occurred in March 1902, and the second largest was in March 1929. The sixty-six floods since 1887 all occurred during the winter and spring months of November through May. Twenty-two of these floods occurred in March, thirteen in January, thirteen in February, and eight in April. There were two floods in May, two in November, and six in December. Natural and regulated flood profiles from miles 248.6 to 266 of the Duck River are shown on exhibit 5.

Observations of river heights at Columbia were begun in 1887 at the site of the old U. S. Highway 31 bridge where the Columbia gaging station is located.[1] Several floods prior to 1887 have been listed for which no height data are available. The table on page 17 lists all known floods since 1814 that exceeded bankful stage at Columbia. It shows that the largest flood of record at Columbia occurred in February 1948, and the second largest was in March 1902. There have been at least fifty-six floods exceeding bankful stage of 32 feet at Columbia in the 80 years of record. All but three of these occurred in the months December through April, with the greatest number in February and March. Only two floods occurred in May, one of which took place in 1967. Natural and regulated flood profiles from miles 136.9 to 185 on the Duck River are shown on exhibit 6. Figure 8 shows portions of the city of Columbia at the crest of the 1955 flood.

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1. Report No. 0-5481, "Floods on Duck River in Vicinity of Columbia, Tennessee," Division of Water Control Planning (May 1957). Hydraulic Data Branch files contain detailed data on most floods that have occurred on the Duck River.

DUCK RIVER NEAR SHELBYVILLE, TENNESSEE

FLOOD CREST ELEVATIONS AND DISCHARGES ABOVE BANKFUL STAGE

1814-1968

Date of Crest	Gage Height - Feet		Peak Discharge	
	Stage	Elevation	Amount, CFS	CFS Per Sq Mile
1814	(a)			
Dec 1847	(a)			
May 6, 1856	(a)			
May 15, 1861	(a)			
Apr 15, 1874	(a)			
Jan 21, 1882	(a)			
Mar 28, 1888	23	707		
Mar 1, 1890	23	707		
Mar 8, 1891	26	710		
Feb 5, 1894	22	706		
Mar 20, 1897	26	710		
Apr 5, 1897	24	708		
Mar 29, 1902	42	725.5	87,000	181
May 24, 1905	24	708		
Feb 24, 1909	26	710		
Apr 30, 1912	26	710		
Mar 28, 1913	23	707		
Feb 3, 1915	23	707		
Mar 5, 1917	23	707		
Jan 24, 1918	22	706		
Jan 2, 1919	24	708		
Mar 14, 1920	24	708		
Apr 2, 1920	30	714		
Apr 18, 1921	24	708		
Mar 3, 1922	25	709		
Mar 11, 1922	24	708		
Jan 4, 1924	22	706		
Dec 26, 1926	26.4	709.9		
Apr 12, 1927	26	710		
Mar 23, 1929	39.6	723.1	70,000	145
Feb 16, 1933	22	706		
Mar 4, 1934	23	707		
Mar 26, 1934	26.5	710		
U. S. Geological Survey stream gage established in April 1934				
Apr 6, 1935	23.37	706.9	17,900	37
Jan 3, 1937	28.25	711.8	24,200	50
Feb 3, 1939	25.25	708.8	18,300	38
Feb 15, 1939	28.08	711.6	22,400	47
Dec 29, 1942	22.48	706.0	15,200	32
Mar 29, 1944	26.14	709.6	20,000	42
Feb 18, 1945	23.78	707.3	16,600	35
Feb 22, 1945	24.88	708.4	17,900	37
Jan 8, 1946	26.59	710.1	20,000	42
Jan 2, 1947	22.30	705.8	14,800	31
Feb 13, 1948	38.40	721.9	62,900	131
Nov 29, 1948	22.10	705.6	13,200	27
Jan 6, 1949	32.80	716.3	34,400	72
Jan 7, 1950	24.73	708.2	16,300	34
Jan 31, 1950	25.71	709.2	17,700	37
Feb 1, 1951	30.56	714.1	27,100	56
Dec 8, 1951	24.67	708.2	16,300	34
Jan 28, 1952	25.65	709.2	17,600	37
Feb 12, 1953	23.31	706.8	14,700	31
Jan 22, 1954	25.81	709.3	17,700	37
Dec 29, 1954	23.92	707.4	14,900	31
Mar 22, 1955	34.84	718.4	37,900	79
Apr 7, 1955	23.50	707.0	14,400	30
Jan 30, 1956	24.32	707.8	15,400	32
Feb 4, 1956	23.58	707.1	14,500	30
Dec 13, 1956	23.47	707.0	14,300	30
Jan 28, 1957	26.21	709.7	18,300	38
Feb 1, 1957	29.04	712.6	23,500	49
Nov 19, 1957	29.02	712.5	23,400	49
Mar 8, 1961	29.89	713.4	25,200	52
Mar 1, 1962	22.50	706.0	13,200	27
Apr 12, 1962	25.44	709.0	17,100	36
Mar 6, 1963	23.20	706.7	14,100	29
Mar 12, 1963	31.90	715.4	31,300	65
Mar 15, 1964	22.98	706.5	13,800	29
Mar 26, 1965	24.95	708.5	16,600	35
Dec 10, 1966	26.47	710.1	19,000	40
Mar 7, 1967	21.95	705.5	12,600	26
May 13, 1967	22.07	705.6	12,700	26

(a) Stage unknown

This table includes all known floods above bankful, elevation 705.5 at the Shelbyville gage, located on the right bank of the Duck River at mile 216.15, 150 feet downstream from Sims Bridge and 5 miles downstream from Shelbyville.

Drainage area at gage is 481 square miles.

On September 2, 1966, datum of gage was changed from 685.51 to 683.51 feet. All stages adjusted to new datum.

DUCK RIVER AT COLUMBIA, TENNESSEE

FLOOD CREST ELEVATIONS AND DISCHARGES ABOVE BANKFUL STAGE

1814-1968

Date of Crest	Gage Height - Feet		Peak Discharge	
	Stage	Elevation	Amount, CFS	CFS Per Sq Mile
1814	(a)			
Dec 1847	(a)			
May 6, 1856	(a)			
May 15, 1861	(a)			
Apr 1874	44	579	42,000	35
Jan 21, 1882	(a)			
U. S. Weather Bureau gage established in January 1887				
Mar 28, 1888	32.4	567.7		
Mar 1, 1890	32.0	567.3		
Mar 9, 1891	36.3	571.6		
Mar 20, 1897	35.8	571.1		
Apr 5, 1897	33.4	568.7		
Mar 29, 1902	48.0	583.3	50,700	42
May 24, 1905	32.6	567.9	26,400	22
Feb 25, 1909	35.3	570.6		
Apr 30, 1912	32.7	568.0		
Mar 28, 1913	32.8	568.1		
Feb 3, 1915	32.0	567.3		
Mar 5, 1917	32.8	568.1		
Jan 2, 1919	33.8	569.1		
Mar 14, 1920	33.7	569.0		
U. S. Geological Survey stream gage established in April 1920				
Apr 3, 1920	35.7	571.0		
Apr 18, 1921	33.1	568.4	26,500	22
Mar 3, 1922	34.5	569.8	27,800	23
Mar 11, 1922	34.0	569.3		
Jan 4, 1924	32.6	567.9		
Dec 26, 1926	37.8	573.1	35,900	30
Apr 12, 1927	36.2	571.5	33,500	28
Mar 25, 1929	43.1	578.4	43,800	36
Mar 4, 1934	31.96	567.3	25,800	21
Mar 26, 1934	35.96	571.3	30,600	25
Jan 2, 1937	39.1	574.4	34,900	29
Feb 5, 1939	35.48	570.8	30,900	26
Feb 17, 1939	34.50	569.8	29,200	24
Mar 30, 1944	35.05	570.4	29,600	24
Jan 1, 1945	33.41	568.7	26,700	22
Feb 23, 1945	37.02	572.4	31,400	26
Jan 9, 1946	40.50	575.8	36,300	30
Jan 3, 1947	32.22	567.6	25,200	21
Feb 14, 1948	51.75	587.1	61,100	51
Jan 8, 1949	35.77	571.1	29,800	25
Jan 7, 1950	37.88	573.2	30,100	25
Feb 2, 1950	39.46	574.8	35,100	29
Feb 3, 1951	36.51	571.8	30,800	26
Dec 9, 1951	34.82	570.2	26,000	22
Jan 29, 1952	33.46	568.8	24,300	20
Jan 22, 1954	36.43	571.8	28,200	23
Feb 23, 1955	33.08	568.4	25,800	21
Mar 23, 1955	44.78	580.1	46,500	39
Feb 6, 1956	33.36	568.7	26,200	22
Feb 18, 1956	34.54	569.9	27,800	23
Dec 15, 1956	33.62	569.0	26,200	22
Feb 2, 1957	40.48	575.8	34,200	28
Nov 20, 1957	33.48	568.8	26,100	22
Mar 10, 1961	37.83	573.2	30,200	25
Feb 28, 1962	39.55	574.9	32,500	27
Apr 13, 1962	36.56	571.9	28,700	24
Mar 7, 1963	32.63	568.0	24,000	20
Mar 14, 1963	37.00	572.3	29,200	24
Mar 27, 1965	35.51	570.8	27,400	23
Dec 11, 1966	37.76	573.1	30,100	25
Mar 8, 1967	32.97	568.3	24,400	20
May 14, 1967	39.75	575.1	32,900	27

(a) Stage unknown.

This table includes all known floods above bankful stage of 32 feet, elevation 567.3 (1955 supplementary adjustment), at the Columbia gage, located at the old U. S. Highway 31 bridge, mile 132.8.

Drainage area is 1208 square miles.

Figure 8 - Columbia, Tennessee, Looking North At Flooded Riverside Section, March 23, 1955

PLANS OF DEVELOPMENT

Early studies of possibilities for development of the main stem of the Duck River, made as part of the general survey of the Tennessee River and its tributaries, were reported in House Document 328, 2d Session, 71st Congress, 1930. In this document six dam sites were identified on the Duck River from about mile 15 to mile 188.

A brief study by TVA in 1951 considered sites at miles 147.7 and 191.3 as offering possibilities for development. However, the projects were not found attractive economically, when evaluated on the basis of benefits which would accrue to navigation, flood control, and power. A more comprehensive investigation, undertaken by TVA in 1965, appraised the opportunities to fully develop the water resources potential as part of the tributary area development program for the region. The reconnaissance survey identified the Columbia site at mile 136.7, the County Line site at mile 191.3 near the probable head of Columbia Reservoir, and the Normandy site at mile 248.6. No sites were identified in the 20-mile reach between Shelbyville and Normandy because of the unfavorable topography.

Feasibility appraisals indicated that the Columbia and Normandy sites should be considered in more detail. The County Line site was less attractive because of apparent foundation problems and was eliminated from further consideration. Extremely tight scheduling of investigations on the upper Duck River precluded a detailed overall appraisal of the water resource development as a system at that time. Therefore, on the basis of information then available, it was decided to concentrate first on the Columbia site and then to focus attention on the Normandy site. Planning report No. 65-100, "The Columbia Project on the Duck River," published in August 1967, presented the results of engineering studies and a definite proposal for development of the Columbia multiple-purpose water control project on the upper Duck River.

NORMANDY DAM AND RESERVOIR

Dam Site

Location--The Normandy Dam site is located on the Duck River at mile 248.6 in Coffee and Bedford Counties, approximately 8 miles north of Tullahoma, Tennessee, and 1.5 miles upstream from Normandy, Tennessee. A secondary road, which passes by the dam site and crosses the Duck River some 1500 feet downstream, connects with other roads leading to Normandy and Tullahoma.

A watershed map and profile of the Duck River showing the Normandy site are shown on exhibit 2.

Topography--In the vicinity of the Normandy site the river channel is generally carved more than 300 feet below the surrounding terrain in a meandering course. The river flows almost due south at the dam site and is about 75 feet in width. The topography at the site is shown on exhibit 12. The right abutment rises abruptly from the river's edge to a crest at about elevation 1070. The left side rises gradually from the riverbank for a distance of 2200 feet horizontally and then sharply upward to a crest at about elevation 1050.

Narrow ridges terminate near the dam site on both sides of the river. The right rim extends northward for about 7000 feet where it joins the main plateau at an average elevation of about 1050. The left rim extends southward for about 8000 feet at an average elevation of about 1050.

Design Flood and Spillway Capacity

The spillway would (1) provide sufficient capacity for all operating levels for flood control operations; (2) discharge the maximum probable flood without exceeding the top of gates level, elevation 880; and (3) provide a freeboard on the structures during a maximum possible flood.

The maximum probable flood at the Normandy Dam site was computed using storm rainfall amounts prepared by the U. S. Weather Bureau. The basis for the computation was the transposition and adjustment of observed storm depths without moisture maximization and with a limited envelopment of transposed data.

The critical combination of maximum rainfall and reservoir level at the Normandy site would occur in the summer when a minimum amount of flood control capacity is available. This maximum probable summer storm would produce 16.7 inches of precipitation in 6 days with 88 percent occurring within a 24-hour period. The peak inflow and outflow for the resulting flood at the dam would be 69,000 cfs. Exhibit 4 shows the estimated inflow and outflow hydrographs for the maximum probable flood and corresponding headwater levels. The outflow hydrograph is, according to one operating plan, appropriate for rare large summer floods; other equally appropriate plans would give different rising and falling limbs for the hydrograph but would not change the peak significantly. Two ~~40~~ 36- by 40-foot high gates with spillway crest at elevation 840 would have discharge capacity sufficient to meet operating needs and to keep reservoir levels from exceeding elevation 880 during the maximum probable flood. The spillway rating curve for this gate arrangement is shown on exhibit 7.

Pool Level Determination

The major factors in determining the pool level for the Normandy impoundment were flood control requirements, compatible recreation potential, and the land-use facilities that were planned for development around the reservoirs by the various program interests. In all plans studied, consideration was given to the storage necessary for water supply and water quality control.

Preliminary data were developed using elevations 860, 880, and 900 for the top of spillway gates. After a determination was made as to the detention capacity required for flood control and the discharges required for water quality control and water supply, it became clear that the reservoir at elevation 860 would not provide enough storage to be useful for the remaining project purposes. The higher level with maximum pool at elevation 900 would have some adverse effects on activities proposed for the Old Stone Fort State Park. Lowering the pool level would eliminate these conflicts and enhance the recreation potential for certain uses of the upper portion of the reservoir. Additional developable land in the lower portion of the reservoir would also be made usable. The most favorable plan of development compatible with all purposes was one with a normal maximum pool at elevation 875. Top of the gates would be set 5 feet higher to allow for year-round controlled flood detention capacity. This would permit higher pool elevations throughout the winter drawdown period. The winter level necessary

to provide flood detention capacity would be elevation 859. Reservoir areas and volumes are shown on exhibit 3.

Reservoir Levels and Project Operation

The optimum project operation in association with the Columbia Reservoir is still under study. Under the current scheme of operation, Normandy Reservoir would be operated compatibly with existing TVA projects to meet system flood control objectives. The annual cycle of operation would be controlled by the requirements of the different project purposes.

Provisions for flood control would require that, except during periods of flood regulation, the maximum multiple-purpose reservoir level be as indicated by the heavy line shown on exhibit 8. This schedule, as tentatively planned, would assure a minimum flood detention capacity equivalent to 6 inches of runoff from the drainage area above the dam on January 1 and, except during flood conditions, the reservoir level would then be at elevation 859. Gradual filling of the reservoir would commence on January 1 with the level no higher than elevation 866 (4 inches of runoff) on April 1, except during a flood control operation. Reservoir filling would continue along the guide curve with the objective of reaching and maintaining a desirable pool level throughout the recreation season. An effort would be made to hold the level to within 5 feet of elevation 875, the normal maximum pool, throughout the recreation season. A minimum flood detention capacity equivalent to 1.6 inches of runoff from the drainage area above the dam would be provided from about May 15 to October 15. The available inflow would be small but would permit water supply and water quality control releases while maintaining acceptable pool levels for recreation use. After October 15, drawdown of the reservoir would begin so that the winter flood detention capacity could be attained not later than January 1.

Substantial releases from the reservoir would be necessary to satisfy a 166-cfs flow requirement at Shelbyville to meet the needs of water supply and water quality control. The effect that these releases would have on the pool levels has been determined by filling studies based on a 45-year period, 1921 through 1965, which show that the reservoir would reach the recreation range between elevations 870 and 875 by June 1 in 41 out of the 45 years. After the summer pool level is reached, the fluctuation in elevation would be moderate except in dry years.

Foundation Explorations

Geologic investigations at the Normandy Dam site began in March 1966 with seismic and surface explorations. Core drilling with wire line drills started in April 1967 and continued intermittently until March 1968. Drilling was concentrated along the proposed axis of the dam, with additional holes 200 feet upstream and downstream from the axis and at two proposed spillway locations (see exhibit 12). In selected holes, electric resistivity and gamma ray logs were run to aid correlation of key horizons and clay seams. When drilling was terminated, 110 holes totaling 14,760 linear feet had been drilled and logged.

A soils investigation program was conducted at the site during September 1967, with a truck-mounted core drill, hand tools, and a portable power auger. The results were considered adequate for project planning purposes.

Geology--Two types of unconsolidated material cover bedrock at the Normandy Dam site--(1) alluvial clays, silts, sands, and gravels deposited by the Duck River and (2) residual clay and rock fragments derived from the decomposition of the bedrock. Beneath the overburden are found four limestone formations--Catheys, Cannon, Hermitage, and Carters. Geologic sections are shown on exhibits 13 and 14.

The Catheys Formation is exposed on both abutments and also is present under the dam between stations 27+00 and 32+00. It consists of over 150 feet of thin-bedded limestone with interspersed bands of shale. Near the bedrock surface many of the thin shale horizons have disintegrated into thin, but persistent, clay seams.

The Cannon Limestone would be the foundation rock for the major portion of the dam and spillway. It is made up of 117 feet of uniformly bedded limestone with beds averaging 1 foot in thickness. It contains less shaly material than overlying or underlying formations and, as a result, solution has taken place along a network of near-vertical joints. Furthermore, certain bedding horizons contain thin clay partings which might act as potential sliding planes. Such seams should be evaluated to determine their effect on the stability of the structure. The Cannon would provide satisfactory material for either rockfill or concrete aggregate.

The Hermitage Formation is not exposed at the site but is present about 50 feet below the Duck River. It consists of 55 feet of thin-bedded, argillaceous

limestone separated by dark-gray to black shale beds ranging in thickness from partings up to a foot. The exploratory drilling disclosed five thin clay seams derived from altered volcanic ash in the Hermitage, but these are so far below the rock surface that they should not affect the stability of the structure. Where the Hermitage Formation is less than 100 feet below the rock surface, it would serve as an adequate bottom for a grout curtain.

The Carters Limestone, though penetrated in the exploratory drilling, is too deeply buried to have any effect on the foundation for the dam.

The rock strata at the site are nearly horizontal. However, there is a 3-degree eastward dip from the right abutment to station 27+00. From stations 27+00 to 31+00 the strata are flat and from 31+00 to the left abutment, at station 42+00, they dip 5 degrees westward. Two major sets of near-vertical joints are prominent structural features because they control the development of solution cavities.

There is no geologic reason why the Normandy site is not suitable for a properly designed dam. Solution cavities along near-vertical joints would have to be treated and the potential effect of clay seams on the stability of the structure would have to be evaluated. These conditions, however, would be encountered at any other potential site in the vicinity. Appendix C contains additional geologic information.

Soils--A limited soils investigation program was carried out to determine in a general way (1) bearing capacities of the soils, (2) the location and extent of any weak foundation material that should be removed, (3) estimated side slopes for an embankment dam, and (4) the location and amount of available borrow material. Enough holes were put down to show that the valley floor between stations 15+00 and 20+00 should be excavated to bedrock to avoid any possible problem with leakage through basal sand and gravel encountered there. Excavation in the remainder of the flood plain may be confined to the upper 2 feet of unstable material, except in isolated weak spots where depths to a maximum of 6 feet might be required. A core trench should be excavated to top of sound rock. Suitable borrow material for an impervious rolled earth fill is available within 1 mile of the dam site. More detailed information on soils is on file in the Singleton Materials Laboratory. However, further investigations will be required for use in detailed design.

Project Features

Different project schemes were evaluated with the main consideration being given to earth- and rock-fill and earth-fill structures. These investigations included an appraisal of chute spillways located on each abutment and an ogee section in the river channel tied into the right abutment. These planning studies were under way at about the same time shear tests were being made on large-diameter cores taken to include weak clay seams present in the rock underlying the Tims Ford Dam on the Elk River. When foundation explorations at the Normandy Dam site revealed similar weak seams, the findings of the Tims Ford investigation were considered applicable in guiding the direction of further planning studies.

Use of a concrete ogee spillway in the river channel was eliminated from consideration early in the studies since it would require deep excavation in order to found the concrete section on sound rock not affected by clay seams. The cost for constructing an ogee spillway was much greater than the cost of constructing a chute spillway on either the right or left abutments. A chute spillway on the right abutment would require more concrete than one on the left abutment. However, the left abutment chute would have to be considerably longer, resulting in a larger quantity of earth and rock excavation. In addition, a bridge would be required over this chute for access purposes. Largely due to the cost of the access bridge, the chute spillway on the right abutment was determined to be the most economical scheme for presentation in the planning report.

Plans for the dam structure included an earth-fill dam and an earth- and rock-fill dam, using a modified version of the dam used at Tims Ford. The amount of suitable earth material available in the immediate vicinity of the site exceeds the required volume for an earth embankment. Therefore, the earth-fill structure was chosen over the earth- and rock-fill structure due to the availability and cost of handling the fill material. Rock excavated for the spillway would be used for riprap on the upstream and downstream faces of the dam.

Appendix A shows the principal features for the Normandy unit.

Dam and Spillway--The dam would consist of a rolled earth-fill embankment 2700 feet long with a height above the flood plain of about 80 feet and a maximum height along the axis of about 110 feet. The upstream and downstream slopes would be 1 on 3.5, flatter than normally required, to allow for the presence of possible weak clay seams in the foundation limestone formations. The crest of the dam would be at elevation 895, or 15 feet above the maximum probable flood.

The chute spillway on the right abutment, as planned, would consist of a concrete weir with two bays containing two 40-foot-high by 40-foot-wide radial gates operated by two hoists. In the upper portion of each radial gate would be located a 6-foot-high by 8-foot-wide hydraulically operated slide gate to release from the surface layer of the reservoir any late spring or summer flood waters that could not be stored in the pool. These gates would ensure that any flood releases during periods of reservoir stratification would be made from the upper layers (epilimnion) of the reservoir having high concentrations of dissolved oxygen. An alternative plan, considered but not adopted, would be to incorporate a sluiceway in the upper portion of the spillway wall along the right abutment. Both the radial and slide gates would be controlled remotely from Pulaski, Tennessee. The radial gates would be separated by a 12-foot-thick pier, with two outer piers each 7.5 feet thick. The pier on the left side of the spillway would be incorporated into a gravity-type retaining wall for the earth embankment of the dam. The top of gates would be at elevation 880, and the crest of the concrete weir would be at elevation 840.

The approach and exit channels would be 92 feet wide along their entire lengths. The 450-foot-long approach would be excavated in rock with its bottom level at elevation 830. The exit, with a slope of 2 on 100, also would be excavated in rock. It would be lined for 430 feet of its length, with a concrete bottom slab and 10-foot-high training walls which should be sufficient to contain floods of magnitudes up to 100-year frequency. This channel would continue an additional 100 feet to the river as an unlined section. It was not practical to extend the discharge channel on a tangent to the river.

There would be a sluiceway through the center pier of the spillway which would be operated as needed for water supply and water quality control. The flow through the sluice would be remotely controlled by a 36-inch-diameter Howell-Bunger valve to ensure a high-dissolved oxygen content. A trash rack and a slide gate at the entrance would afford protection and permit closure for inspection and maintenance.

Construction of the dam and spillway would involve the removal of about 180,000 cubic yards of earth and about 170,000 cubic yards of rock. Some of the excavated rock could be used as slope protection material for the dam and diversion dike. The earth-fill embankment would require 1,800,000 cubic

yards of fill and the chute spillway some 30,000 cubic yards of concrete. The bulk of the earth-fill would come from borrow areas near the dam site. A layout of the dam and spillway is shown on exhibit 15.

Access--Access to the Normandy Dam site area would be by way of a newly constructed county road extending northeast from the town of Normandy along the left bank of the Duck River. This road, which would pass just below the dam site and connect with the existing Riley Creek Road into Tullahoma, would be constructed as part of the highway relocation program. Visitors' facilities and a picnic area would be located on the left bank of the reservoir just upstream from the dam. A grounds maintenance center would be required.

Reservoir

Extent--The Normandy Dam would create a reservoir which at normal maximum pool, elevation 875, would have a volume of about 117,000 acre-feet, a shoreline length of about 72 miles, and a surface area of about 3200 acres. Of the total area inundated by the reservoir, about 2800 acres is land planted in pasture or hay crops. The remainder is woodland.

Studies show that acquisition of some 170 tracts containing about 9200 acres would be required. There would be about 3500 acres below the normal maximum flood elevation for the reservoir and about 5700 acres between the normal maximum flood elevation and the purchase boundary. The latter would be required for the project to minimize severance damages, to avoid leaving in private ownership land which would be without access, and to assure effective development and use of the shoreline for purposes of public benefit. Following tract realignment after impoundment of the reservoir, portions of this acreage could be disposed of, subject to appropriate conditions and restrictions. Included in this land above the maximum flood elevation are areas with a significant potential for recreation development.

Clearing--The wooded areas in the reservoir, totaling some 500 acres, would be cleared from the riverbed to elevation 877, two feet above the normal maximum pool.

Vector Control--The steepness of the general terrain in the vicinity of the reservoir, along with the uncertainty of reservoir levels during the larva-growing season, precludes the practicality of deepening and filling

various areas around the reservoir. A minimal amount of marginal drainage would be required in areas contiguous to the reservoir and is planned as part of project construction, together with mowing of regrowth that may occur following clearing and before initial impoundage.

Pool level studies show that the reservoir in most years would not fill to elevation 875 until well along in the growing season. As a result, it is expected that a mosquito-inspection service and repetitive larviciding program will be required. This has been taken into consideration in setting up the operating costs for the reservoir.

Adjustments--Construction of the Normandy Reservoir would require the relocation of 90 families and 1 cemetery. Practically all of the dwellings and buildings in the reservoir are old but in fair condition.

Construction of the Normandy unit would have varying effects on the highway systems of Coffee and Bedford Counties. Some roads would be abandoned, some relocated, and others improved. It is estimated that there would be about 14 miles of relocations and improvements, all of which are secondary roads. Two of the relocations would have major bridge crossings of Normandy Reservoir.

The minimum level for the roadway relocations would be elevation 885, which is 5 feet above top of gates. The bridges would require a clearance for navigation above the normal maximum pool, elevation 875, to the low steel of the structure. The bridges crossing the Duck River would provide the standard secondary channel clearance of 15 feet while those crossing the tributaries would provide at least 6 feet.

Utility relocations would include power transmission and distribution lines and telephone lines. No evidence has been found of natural gas lines that would be affected by the project.

There are no quarries operating in the Normandy Reservoir area although the Ordovician Limestone in this area is suitable for quarrying. Sand and gravel occur at points along the Duck River in the Normandy area in sufficient quantities to have economic value. At present, there are only two small-scale sand-gravel operations near Duck River mile 251 which would necessitate compensation due to construction of the Normandy unit.

THE COLUMBIA DAM AND RESERVOIR

Dam Site

Location--The site for Columbia Dam is located on the Duck River at mile 136.9 in Maury County, Tennessee. It is approximately 2 miles east of Columbia, Tennessee, by way of a county road which crosses the river just downstream from the site. A watershed map and profile of the Duck River showing the Columbia site are shown on exhibit 2.

Topography--The Duck River in the vicinity of the Columbia site follows a meandering course in a channel generally carved more than 200 feet below the surrounding terrain. At the dam site the river flows almost directly north and varies in width from 200 to 300 feet. The topography of the site is shown on exhibit 16. The right abutment rises gradually from a narrow flood plain to a general level at about elevation 650, while the left side rises gently from the riverbank for a distance of 400 feet horizontally and then abruptly upward to a crest at about elevation 700.

Narrow ridges flank the site on both sides of the river. The right rim extends eastward for about 23,000 feet at an average elevation of about 850. The left rim extends southward for about 13,000 feet at an average elevation of about 720.

Design Flood and Spillway Capacity

The spillway will (1) provide sufficient capacity at all operating levels for flood control operations, (2) discharge the maximum probable flood without exceeding the top-of-gates level, elevation 635, and (3) provide a freeboard on the structures during a maximum possible flood.

As with Normandy, the maximum probable flood at the Columbia Dam site was computed using storm rainfall amounts prepared by the U. S. Weather Bureau. Likewise, the critical combination of maximum rainfall and reservoir level would occur in the summer when a minimum amount of flood detention capacity is available. The maximum probable summer storm would produce 15.3 inches of precipitation on the 986-square-mile drainage area between the site and Normandy Dam in a 3-day storm period. The peak inflow and outflow would be 170,000 cfs. Exhibit 4 shows the estimated inflow

and outflow hydrographs for the maximum probable flood and corresponding headwater levels. The outflow hydrograph is, according to one operating plan, appropriate for rare large summer floods; other equally appropriate plans would give different rising and falling limbs for the hydrograph but would not change the peak significantly. Discharge capacity sufficient to meet operating needs and to keep pool levels from exceeding elevation 635 in the maximum probable flood following normal operating rules can be obtained with five 40- by 40-foot gates with spillway crest at elevation 595. The spillway rating curve for this gate arrangement is shown on exhibit 7.

Pool Level Determination

The major factors in determining the pool level for the Columbia Reservoir were flood control requirements, compatible recreation potential, and reservoir land and relocation costs. In all plans considered, provision was made for the necessary storage for water supply and water quality control. Reservoir volumes would be such that these features would have no significant effect on the pool level determination. In early studies, power production was considered as an integral part of the project operation; and studies were made to determine optimum power installations. However, estimates revealed that the justifiable expenditure was much less than the direct cost of power and no further consideration was given to that purpose in planning the unit.

Pool level studies were made, using elevations 630, 635, 640, and 650 for the top of spillway gates. Cost estimates for these various schemes gave the necessary background for evaluating an economically feasible project that would satisfy the many program interests so important to its success.

Since the Columbia Reservoir would be planned for multiple-purpose use, optimum levels for all purposes were not possible; therefore, the most favorable scheme that could be developed was one of compromise. Particular consideration was given to creating a reservoir for the highest quality recreational opportunities compatible with flood control operation requirements. Along this line, studies showed that land for recreation purposes, primarily downstream from Interstate 65, could best be developed with a normal maximum reservoir level around elevation 630. This also appeared to be compatible with other program interests, and estimates showed reservoir costs to be reasonable at this elevation.

The optimum operation of Columbia and Normandy Reservoirs as a system to meet the requirements of different program purposes remains under study. The most favorable scheme considered to date for Columbia Reservoir would have top of gates at elevation 635 and the normal maximum pool level at elevation 630. The storage volume between these two elevations would allow for year-round controlled flood detention capacity. This would permit higher pool elevations throughout the winter drawdown period. The winter level necessary to provide flood detention capacity would be elevation 603. Reservoir areas and volumes are shown in exhibit 3.

Reservoir Levels and Project Operation

The Columbia Reservoir would be an integral unit of the TVA water control system and would be operated with the system to meet flood control requirements. In addition, the yearly cycle of operation would be planned to attain the levels needed for recreation and fish and wildlife.

As tentatively planned, and as shown on exhibit 8, the schedule would provide on January 1 a flood detention capacity equivalent to 5.4 inches of runoff between the site and Normandy Dam. Except during flood conditions, the reservoir level would then be at elevation 603. This elevation would be held until February 1, after which time the pool level would be raised gradually along the guide curve, reserving on April 1 a detention capacity equivalent to no less than 3.6 inches of runoff from the uncontrolled drainage area. At this time the reservoir normally would be no higher than elevation 618.5. After April 1 the reservoir would be filled along the guide curve with the objective of reaching and maintaining recreational pool levels within about 5 feet of the normal maximum pool (elevation 630) throughout the summer months. A minimum flood detention capacity equivalent to 1.3 inches of runoff from the drainage area between the Columbia and Normandy Dams would be maintained from about May 15 to October 15. Normal inflow would be relatively small but would still allow water supply and water quality releases while maintaining a desirable pool for recreation or other needs. After October 15, drawing of the reservoir would begin in order to restore the winter flood detention capacity not later than January 1.

Releases from the reservoir for water supply and water quality control are expected initially to be in the order of 200 cfs. These releases are to be gradually increased over the life of the project, as required, to an expected ultimate of 300 cfs. Filling studies were made for a 45-year period, 1921 through 1965, to determine the effect of the 300-cfs release on pool levels. They show that the reservoir would reach the recreation range between elevations 625 and 630 by June 1 in 35 out of the 45 years. Initially, with 200-cfs releases, the reservoir would be affected to a lesser degree. After the summer pool level is reached the fluctuations would be small even in dry years.

Foundation Explorations

Geologic investigation of the Columbia Dam site began in March 1966 with seismic and surface explorations along an axis at mile 136.7. In June 1966 foundation exploration with wire line drills began on the right bank of the river. It soon became apparent that the axis of the dam should be moved upstream to mile 136.9 and slightly realigned (exhibit 16). Drilling was concentrated then along the new axis and the left and right abutments. Additional drilling was done on the flood plain and in the area of a possible chute spillway. When drilling was concluded, 161 holes totaling almost 18,000 linear feet had been drilled and logged.

A soils investigation program adequate for project planning purposes was conducted at the site early in October 1966. A truck-mounted core drill, hand-probing tools, and a portable power auger were used in this investigation.

The results of the foundation exploration programs are discussed briefly in the following paragraphs.

Geology--Two types of unconsolidated material cover the bedrock at the Columbia Dam site: (1) alluvial clays, silts, sands, and gravels deposited by the Duck River and (2) residual clay and rock fragments derived from the decomposition of the bedrock. Beneath the overburden are found four limestone formations--Hermitage, Carters, Lebanon, and Ridley--only the latter two of which would be significant in construction. Geologic sections are shown on exhibits 17 through 21.

The Hermitage Formation near the dam site is exposed chiefly at elevations above the normal pool level, and the formation consists of about 70 feet of thin beds of argillaceous limestone separated by dark-gray to black shale beds ranging in thickness from partings up to a foot.

The Carters Limestone is exposed on both abutments and rims of the site above approximately elevation 620. Most of the limestone beds are massive, ranging from 1 foot to 4 feet thick, and are separated by thin seams of clay or shale. In areas not protected by the Hermitage Formation a deep, rectilinear, joint-controlled solution pattern has developed that will create foundation problems. Extensive treatment will be required to prevent leakage beneath any part of the dam located directly on this formation. Sinkholes are common in the outcrop area of the Carters in the right rim.

In general, rock quarried from the Carters Formation makes excellent riprap, concrete aggregate, filter material, and road material. However, it should be tested for abrasion and sodium sulphate losses before it is accepted for use in construction of the Columbia Dam.

Lebanon Limestone is present in both abutments below elevation 620 and under the flood plain and river channel. It is about 105 feet thick and is composed of beds of limestone averaging 2 to 3 inches thick separated by beds of calcareous shale ranging up to 2 inches thick. Where the formation is covered by the Carters, weathering is limited to partial decomposition of a few thin shales. In the flood plain more pronounced deterioration was observed, particularly in the fault zone under the right flood plain where some areas of total decomposition were found. Foundations of a dam placed upon the Lebanon Formation should be further evaluated since shear values on some beds may be low, and many bedding planes contain material that becomes slippery when wet. In favorable locations, the top 30 feet of the Lebanon Formation may be suitable for use as road material, filter material, or fill; but none of it would be suitable for exposed riprap.

The Ridley Limestone is not exposed at the dam site, but it is about 28 feet below the top of rock in the river channel and would be involved in any grouting under the dam. Most of this formation consists of massive beds of limestone separated by thin shale partings. About 10 feet below the Lebanon-Ridley contact there is a very persistent weathered bedding plane with which thin, open cavities are associated in some places.

The rock strata at the dam site are essentially horizontal, but in many places they are obscured or modified by minor warping or cross folding. Two major sets of joints at nearly right angles to each other are prominent structural features because they control the development of solution cavities.

At the dam site, the most prominent structural feature is a multiple-fault zone on the eastern side of the river (exhibit 17). A concentration of solution features extends to the east for some distance beyond this fault zone, and appreciable solution appears to be associated with the zone.

There is no reason why the foundations at the Columbia site, mile 136.9, could not support a properly designed hydro structure. The physical quality of the rock will remain very similar within several thousand feet upstream or downstream from the site. The fault zone might be avoided by moving upstream some 2000 feet, but it appears to follow the river downstream for a considerably greater distance. Appendix C contains additional geologic information.

Soils--Generally, enough holes were augered to determine (1) bearing capacities of the soils, (2) the location and extent of any weak foundation material that should be removed, (3) estimated side slopes for an embankment dam, and (4) the location and amount of available borrow material. The investigation disclosed a small area on the right flood plain that should be excavated to elevation 554. The remainder of the area beneath the dam should be stripped and a core trench excavated to the top of sound rock. Suitable borrow material for an impervious rolled earth fill is available within 1 mile of the dam site. More detailed information on soils is on file in the Singleton Materials Laboratory. However, further investigations will be required for use in detailed design.

Project Features

A number of project schemes were evaluated in the course of selecting a type of dam structure which would be suitable for the foundation conditions at the site and at the same time would be most economical to construct. Simultaneously with studies of the Columbia Dam, shear tests at Tims Ford Dam site, on the Elk River, were being made on large-diameter cores taken to include weak clay seams present in the rock underlying the dam. When foundation explorations at the Columbia Dam site revealed similar weak seams, the findings of the Tims Ford investigations were considered applicable in guiding the direction of further planning studies.

In early studies, a concrete, ogee spillway was planned across the river channel, with earth-fill embankments extending to each abutment. However, this would require considerable rock excavation and a large volume of

substructure concrete to locate the spillway on sound rock not affected by clay seams. Further studies indicated that a chute spillway could be placed on the right abutment with a more reasonable foundation excavation pattern. The chute could be skewed to fit the natural terrain and to provide good exit conditions. A rock-fill and an earth-fill dam were subsequently considered in conjunction with the chute spillway. The large quantities of rock excavation required for the spillway and the shorter length of the diversion culvert through the dam made a strong case for use of a compacted rock-fill structure. However, a diversion scheme was later devised which eliminated the need for this culvert; and it was determined for planning purposes that the estimated cost of the project was less for an earth-fill dam in conjunction with a concrete chute spillway.

A summary of principal features for the Columbia unit is shown in appendix A.

Dam and Spillway--The dam would consist of a rolled earth-fill embankment 1575 feet long with a height above the flood plain of about 80 feet and a maximum height of 105 feet along the axis. The crest of the dam would be at elevation 645. Upstream and downstream slopes, which would be flatter than normally required, were estimated at 1 on 3.5 to make allowance for the presence of possible weak clay seams in the Lebanon Limestone Formation. A low, 500-foot-long embankment also would be required between the spillway and right abutment.

The chute spillway, as planned, would consist of a concrete weir with five bays containing four radial gates ~~40~~ 41 feet high by 40 feet wide, operated by five one 3obe 20 x 40 wide hoists which would be remotely controlled. The gates would be separated by piers, the outer two 7.5 feet thick and the inner two ~~10.5~~ 7.5 feet thick. The spillway would be flanked by training walls 7.5 feet thick, also serving as retaining walls for the abutting earth embankments. The top of gates would be at elevation 635, and the crest of the concrete weir would be set at elevation 595.

An upstream approach channel, varying in width from 300 feet at its entrance to 236 feet at the spillway weir, would be excavated to elevation 585. The 545-foot-long concrete chute would narrow from a width of 236 feet near the spillway crest to 150 feet at its lower end. This width would continue an additional 550 feet to the river as an unlined section excavated in rock.

The sluiceway, through two inner piers of the spillway, would provide a means for releasing water for water supply and water quality control. Each of the two sluices would be provided with a remotely controlled 36-inch-diameter Howell-Bunger valve so that any water discharged would have a high dissolved oxygen content. A trash rack and a slide gate at the entrance would afford protection and permit closure for inspection and maintenance. Further studies will be necessary to determine if special structures are needed for passing any late spring or summer floodwaters that cannot be stored in the pool.

Construction of the dam and spillway would involve the removal of about 480,000 cubic yards of earth and 340,000 cubic yards of rock. This material would be used in the dam embankment and diversion dikes. The earth-fill embankment would require, 1,110,000 cubic yards of fill and the chute spillway some 40,000 cubic yards of concrete.

A layout of the dam and spillway structures is shown on exhibit 22.

Cedar Creek Structures--A small constant-level impoundment, with pool at elevation 630.5, on Cedar Creek within Columbia Reservoir would be included as part of a waterfowl management and refuge area in conjunction with the other project features. The relationship of Cedar Creek Dam to the Columbia Reservoir is shown on exhibit 11. The earth- and rock-fill dam, shown on exhibit 23, would be 1300 feet in length, including the spillway, with a maximum height of about 28 feet. Slopes have been shown as 1 on 2 both upstream and downstream but might be modified when more is known about foundation conditions. The top of the embankment would be at elevation 635. The spillway, with a concrete weir having a crest at elevation 630.5, would be excavated in rock through the right abutment of the dam. Because these structures would be located within the Columbia Reservoir they would be subject to overtopping from either side. A 3- by 6-foot sluice gate at the upstream toe of the dam and a 30-inch-diameter pipe through the dam would permit unwatering the impoundment. The sluice gate would be controlled from the top of the dam. A foundation exploration program will be necessary at the dam site prior to initiation of detailed design.

Access--Access to the Columbia Dam site area is by way of a county road which leads east out of Columbia (exhibit 11). It would be improved and a bridge across the Duck River just downstream from the dam would be replaced

as a part of the highway relocation program. Access to the dam itself would be provided by newly constructed roads located on each side of the river. A visitors' building and a picnic area would be located on the right bank and a shelter with information plaque on the left bank. A grounds maintenance center would be required.

Reservoir

Extent--Columbia Dam would create a reservoir which at normal maximum pool, elevation 630, would have a volume of about 294,000 acre-feet, a shoreline length of about 236 miles including islands, and a surface area of about 12,600 acres. Of the total area inundated by the reservoir, almost 11,000 acres is land planted in pasture or hay crops. The remainder is woodland.

Based on a profile varying from elevation 635 (top of gates) at the dam to elevation 645 at the head of the reservoir, studies show that acquisition of some 635 tracts containing about 30,500 acres would be required. Of the total, about 12,500 acres of land lying above the profile would be required for the project to minimize severance damages, to avoid leaving in private ownership land which would be without access, and to assure effective development and use of the shoreline for purposes of public benefit. Following tract realignment after impoundment of the reservoir, portions of this acreage could be disposed of subject to appropriate conditions and restrictions. Included in the land above the flow profile for the Columbia Reservoir is an area that would be reserved for the Cedar Creek Waterfowl Refuge and areas with a significant potential for recreation development.

Clearing--The wooded areas in the reservoir, totaling some 1700 acres, would be cleared from the riverbed to elevation 632, which is 2 feet above the normal maximum pool.

Vector Control--Although the general terrain around the reservoir is rolling to hilly, there are several extremely flat areas in the vicinity of river bends and along tributary streams within the proposed reservoir. At normal maximum summer pool, elevation 630, there would be some 600 acres of water less than 3 feet deep. Shoreline improvement by deepening and filling is planned, where feasible, to reduce the mosquito breeding potential of these areas. Drainage of limesink pools within and contiguous to the reservoir is also planned as part of project construction, along with mowing of regrowth that may occur following clearing and before initial impoundage.

Operation studies indicate that the reservoir will not fill to elevation 630 most years until well along in the growing season. As a result, it is expected that an annual program of larviciding and control of plant growth will be required.

Adjustments--Construction of Columbia Reservoir would necessitate the relocation of about 350 families and 14 cemeteries. Most of the reservoir area is in farm land, the dwellings and farm buildings on which are old but generally in fair condition. Near Columbia, however, particularly in the Fountain Heights area and Blue Springs community, there are a number of new residences that are relatively expensive.

The proposed construction would require building a number of new roads, adjusting others, and abandoning some which no longer would serve a useful purpose. A total length of about 33 miles of highways would be affected, the majority of which are secondary roads. The balance includes primary State and Federal highways together with approximately 3 miles of interstate highway. It is planned to raise in place portions of Interstate Highway 65 north of the Duck River near mile 151. The two bridges spanning the river probably will have to be razed and rebuilt. (See figure 9.)

The minimum elevation for roadways would generally be 5 feet above top of gates, or elevation 640. Low steel for bridge crossings of the Duck River would be at elevation 645, fifteen feet above the normal maximum pool. A minimum underclearance of at least 6 feet will be provided for on tributary crossings.

No railroad relocations would be required. However the Louisville and Nashville railroad crossings of Goose and Hurricane Creeks, south of Columbia, and the Duck River at mile 184 would require riprap protection of the exposed banks.

Utility relocations would include several power transmission and distribution lines, three large natural gas lines of the Texas Eastern Transmission Corporation, and telephone lines. Cost estimates are based on the assumption that the flooded sections of the gas lines would be replaced with heavier pipe and weighted in place. A 500-kv transmission line crosses the reservoir area in a north-to-south alignment at about river mile 147.4. Only one short section will require adjustment in order to provide proper clearance above Columbia Reservoir.

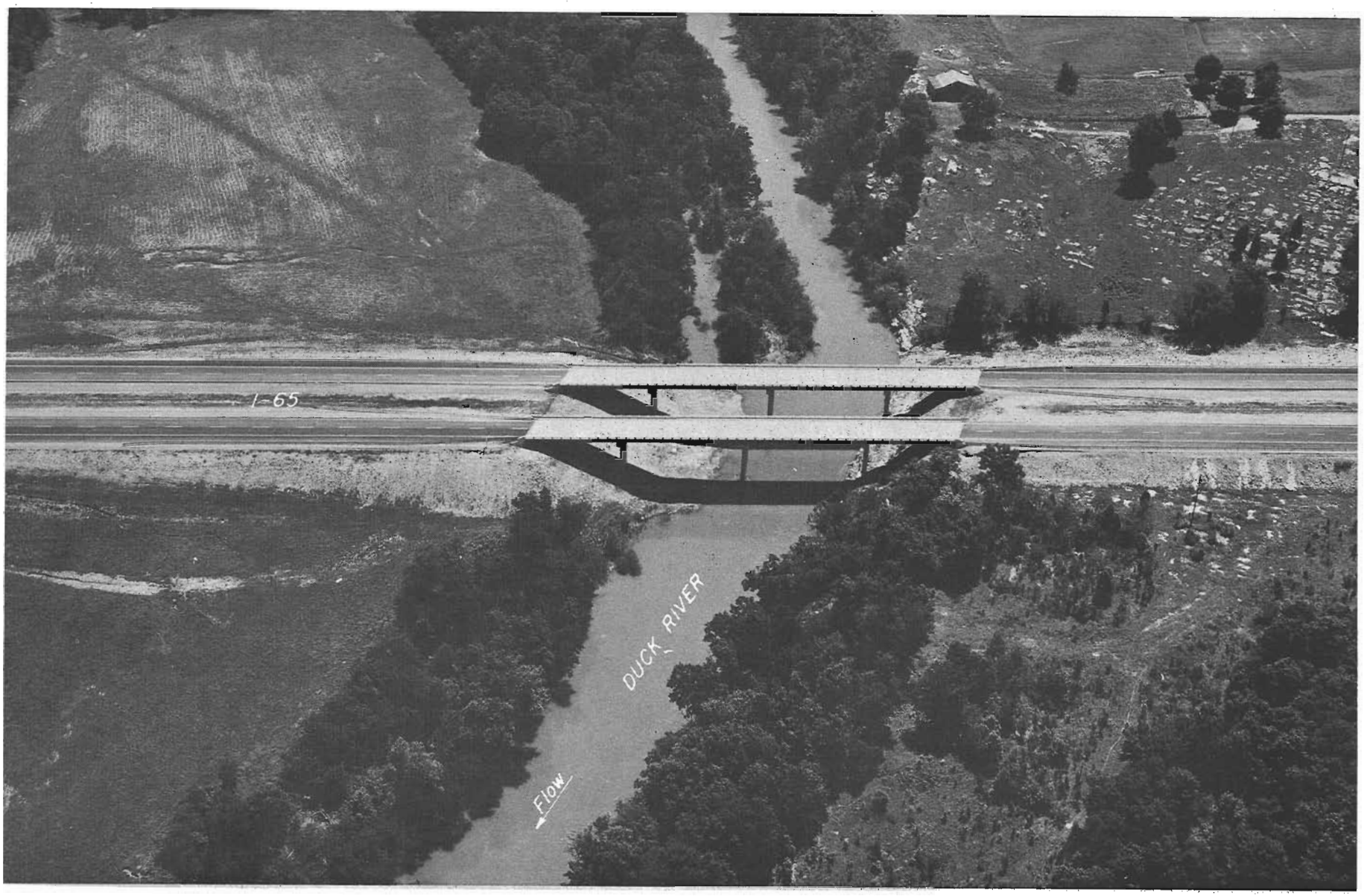

Figure 9 - Interstate Highway 65, Duck River Crossing, Looking Upstream

No operating quarries and no workable deposits of sand or gravel are located in the reservoir areas. However, a major mining company does hold valid leases for zinc within 4.5 miles of the upstream limit of the reservoir. Phosphate deposits are located, for the most part, downstream from the project; but any that might be in the reservoir areas would be well above pool level.

CONSTRUCTION PROGRAM

As planned, Normandy and Columbia Dams would be constructed at the same time, with equipment being moved from one site to the other in the most efficient sequence of operation. Land acquisition for both reservoirs would begin shortly after project authorization. Reservoir adjustments would be initiated almost immediately at Columbia, where relocations would be more numerous. The schedule for Normandy calls for a construction period, including land acquisition, of about 3.5 years. The Columbia construction would require a longer period--about 4.5 years. The construction planning schedule and diversion schemes are shown on exhibit 24.

Construction of each dam would be accomplished in three major stages. The first stage would consist of building the spillway gate structure and chute and the entrance and exit channels. One of the spillway bays would be kept low to accommodate streamflow during the third stage of construction. A culvert, to be used for diversion during the second stage, would be built on the left flood plain and construction started on the upstream dike which would be part of the embankment of the dam. During the second stage of construction the river would be diverted through the culvert, and the dike completed across the river. The culvert then would be plugged and the flow of the river diverted through the spillway. Another dike, downstream from the dam site, would complete the protection of the area during the third construction stage against a 5-year flood. Construction of the main embankment would proceed during the third stage, with all streamflow being diverted through the low block in the spillway. Should headwater elevations reach the spillway crest, all spillway bays would be available to divert the flow.

Final closure would be accomplished by blocking the flow of water through the low spillway bay by bulkheads, and then completing this bay by placing concrete to the required crest level. Excessive streamflow could be diverted over the completed spillway bays. With closure scheduled for January 1, the reservoir would be filled to normal operating levels as rapidly as streamflow would permit. Work on recreational facilities and on the Cedar Creek Waterfowl Refuge would be secheduled so as to be completed when the reservoirs are impounded.

ESTIMATE OF COST

The total construction cost of the Duck River project is estimated to be $73,500,000. A detailed cost estimate showing a breakdown of costs for the Normandy and Columbia units is contained in appendix B. The following is a summary of the project cost by major items.

Item	Estimate of Cost
Land and acquisition	$17,362,000
Reservoir preparation and relocations	18,579,000
Dams and spillways	10,773,000
Other structures and improvements	3,600,000
Total Direct Cost	50,314,000
General expense and contingencies	23,186,000
Total Estimated Cost of Construction	$73,500,000
Allowance for interest during construction	5,500,000
Total Estimated Cost for Economic Analysis	$79,000,000

The estimated cost is based on a 4.5-year construction period, with a start in 1970, as shown on exhibit 24. Land prices reflect the general real estate price levels escalated to 1971. All other costs are based on estimates of wages and prices projected to 1972. Should the construction period be extended, the project cost would very likely be increased. The cost of possible development of the 15 miles of scenic stream below Normandy Dam is not included.

OPERATION AND MAINTENANCE

The operation of the gates and Howell-Bunger valves at each dam would be controlled remotely from the office of the Hydraulic Data Branch at Pulaski, Tennessee. Headwater and tailwater gages would be located at the dams. Additional stream gages and water quality monitoring stations would be located downstream to assist in control operations. A stream gage at Duck River mile 221.4 and a water quality monitoring station at about Duck River mile 215 would be required at the city of Shelbyville to determine the water quality releases required from Normandy Reservoir. At Columbia the existing USGS stream gage at Duck River mile 132.8 and a new water quality monitoring station near Duck River mile 122 would be required to control releases from Columbia Reservoir. Local flood control operations would be governed to a large degree by high-water conditions at the towns of Shelbyville, Columbia, and Centerville, with additional consideration in early April and late November to agricultural land on the flood plains downstream from the dams.

Data from the various instruments would be received by radio at Pulaski and there made available for communication to the River Control Branch at Knoxville. The radio system would become a part of the Valley-wide hydrologic network system, with the intention of eventual expansion so that water levels and the gate positions could be read directly in Knoxville.

The estimated annual operation and maintenance costs for the Duck River project are as follows:

Dam reservations	$125,000
Structures and equipment	40,000
Reservoir public-use facilities	140,000
Vector control	35,000
Total	$340,000

BENEFITS

The Duck River project would provide flood control benefits to the TVA system and local area; would improve the quality and quantity of water available for municipal and industrial use; would create recreational opportunities, including fishing and hunting, in and around the reservoirs; would make available land for development along the shoreline for public and private use; would result in improved highway travel in the project area; and would provide higher wage employment for the subemployed in the area. The total annual benefits for all purposes are estimated to be $4,960,000. They have been computed using an interest rate of 4-5/8 percent and a project life of 100 years.

Optimum development of the project and realization of its maximum contribution to the economy of the area depend upon a joint effort by the Upper Duck River Development Association, the Tennessee Upper Duck River Development Agency, the Upper Duck River Regional Planning Commission, TVA, and appropriate state agencies.

Flood Control

The Duck River is the largest tributary of the Tennessee River presently without reserved flood detention capacity. This tributary produces large floods which cause significant damages to urban areas and agricultural lands along the stream. In addition, the flow from the tributary can add materially to flood crests on the lower Tennessee, Ohio, and Mississippi Rivers. The benefits resulting from the use of the flood detention capacity planned for the Duck River project have been considered in two parts, (1) those adding to the effectiveness of the TVA water control system and (2) those accruing to the local areas downstream from the dams. The total value of the flood control benefits has been estimated at $365,000 annually.

System Benefits--The project would increase TVA system effectiveness by assisting in (1) controlling lower Ohio and Mississippi River floods by increasing the amount of capacity upstream from Kentucky Dam, (2) reducing the amount of flooding along the Tennessee River downstream from Kentucky Dam, primarily at Calvert City, Kentucky, and (3) increasing the operating efficiency of Kentucky Reservoir during large floods when low net heads on the spillway restrict preflood

drawdown. The 1181-square-mile drainage area of the Duck River upstream from Columbia Dam site comprises 16 percent of the total local drainage area between Pickwick Landing and Kentucky Dams and 34 percent of the total Duck River drainage area.

The flood control reservation available on January 1 in the two reservoirs would amount to 343,000 acre-feet, equivalent to about 5.4 inches of capacity on the total drainage area at the Columbia Dam site. It is estimated that this reservation would have an average annual unit value of $0.52 per acre-foot, resulting in an average annual benefit of $180,000.

Local Benefits--The project would reduce urban flooding at cities along the main stem of the Duck River. The detention capacity in Normandy Reservoir in combination with the existing protective levee at Shelbyville would provide considerable flood reduction for that city, which is 27 miles downstream from the dam. The portion creditable to the project would be relatively small. The detention capacity in Columbia Reservoir would reduce flooding at the city of Columbia, immediately downstream, and at Centerville, some 65 miles downstream from the site. It would reduce the 1948 flood of record through Columbia and future floods in the order of 300-year frequency to essentially nondamaging stages. At Centerville the protection would be less. However, the present flood plain provision in this city's zoning ordinance and subdivision regulations might be revised to take advantage of the reduced flood flows. Based on a field appraisal of potential flood damages to residential, business, and industrial properties at the three cities, the annual urban benefits assignable to the flood-lowering effect of the project are estimated to be $75,000. The reduction at the town of Columbia represents about 98 percent of the total potential at that city. A benefit would accrue also to about 400 acres of land just downstream from Normandy Dam, between miles 246 and 248 of the Duck River, and to about 1,200 acres, between miles 130 and 135, in the city of Columbia, that would be enhanced because of the protection provided by the reduction in flooding. This benefit has been estimated at $70,000 annually. It is expected that this acreage would be developed for nonresidential use which would add to employment and income in the area.

In addition to the local urban benefits, the project would reduce flood damages to roads and bridges along the Duck River. The amount of this benefit has been estimated at $5,000 annually, based on data obtained from county highway commissioners. Part of the reduction in damages would take place in

reservoir areas where the existing bridges that are subject to damage would be adjusted as part of the project construction.

The project also would produce agricultural benefits by reducing the potential flooding along the Duck River downstream from the dams during the period November through April. At present, flood damages to agriculture along the flood plain occur principally during the late winter and spring months. Large overflows during this period cause considerable soil erosion on plowed land, cause destruction of fences, delay crop planting, and destroy early crops. Crop-season flooding is of little significance except possibly in early April and late November. While the project would reduce flooding for a considerable distance downstream from the dams, the reduction in damages would be most significant on 4000 acres of land located between Normandy Dam and the city of Shelbyville, on 2000 acres between Shelbyville and Duck River mile 207, and on 3700 acres between Columbia Dam and the Maury-Hickman County line. Land which would be enhanced because of anticipated industrial use is not included in this acreage. The agricultural benefit is estimated to amount to about $35,000 annually. The sum of all local flood control benefits is estimated to be $185,000.

Shoreline Development

Approximately 18,000 acres of land adjacent to the reservoirs would be acquired in order to prevent unreasonable severance damages, avoid undue expense in providing access to isolated tracts, and assure maximum development and use of the reservoirs for purposes of public benefit. The project would enhance the value of approximately 9000 acres of this land. This enhanced acreage, made up of remnants of tracts formerly in separate ownerships which would be joined and provided with reasonable access, would be made available for those uses that would most effectively serve to stimulate economic development in the region. In addition, some 1500 acres of adjoining land not acquired for the project would be enhanced by the project and related development.

These elements, taken together, would produce shoreline development benefits which have an estimated average annual value of $370,000. Of this total, about $340,000 is related to the land acquired for the project, and $30,000 represents the increased value occurring on adjoining land. This benefit has been adjusted to prevent potential overlap with other categories of project benefits.

Water Quality Control

On the premise that the municipal and industrial waterborne wastes originating in the upper Duck River area during the next 100 years receive both primary and secondary treatment, the treated effluents at Shelbyville and Columbia will impose a residual load on the main stream of the Duck River in excess of the assimilative capacity of the unregulated stream at times of low flow during warm weather.

Minimum streamflow as used in the water quality phase of these investigations is defined as the minimum average flow over a continuous period of 7 days which statistically recurs once in 10 years (7-day, 10-year minimum flow). Under present unregulated conditions the 7-day, 10-year minimum flow is 50 cfs at Shelbyville and, due to evapotranspiration losses from the river, only 30 cfs at Columbia. Studies indicate that 155 cfs of clean water will be the minimum continuous streamflow required at both Shelbyville and Columbia during the period 1975 through 2075 to maintain water quality at acceptable levels in the Duck River during 19 years out of an average 20-year period. These flow requirements are based on projections of anticipated waste loads to be discharged from secondary waste treatment plants. Any releases from storage for water supply purposes must be provided in addition to these water quality control requirements. The storages required to provide these flows are estimated to be about 17,600 acre-feet in the Normandy impoundment and about 4,000 acre-feet in the Columbia impoundment. The water quality storage in Columbia Reservoir is only that which would be required to compensate for the loss of water that normally occurs in the river reach between Shelbyville and Columbia during dry periods.

The least-cost alternative to flow regulation for maintaining acceptable water quality downstream from Shelbyville and Columbia is tertiary treatment at both Shelbyville and Columbia, plus flow regulation from a single-purpose reservoir located upstream from Shelbyville. The present worth of the average annual cost of this least-cost system is estimated to be about $365,000, which is the measure of the benefit attributable to the water quality control features of the Duck River project. A supporting report entitled "The Potential Impact of Water Quality of the Duck River Project" describes in detail the water quality aspects of the project.

Water Supply

Projections for the 4-county upper Duck River area indicate that over the 100-year period, 1975 through 2075, the population will increase from about 135,000 to almost 375,000. At the same time, the average daily per capita water use is expected to increase from 140 to 200 gallons. The five large cities in the area should be prepared to meet the water supply demands of these people through the water grid system, the first phase of which is now nearing completion. In turn, the Duck River project is needed to assure an adequate supply of water for the grid system, as well as for large self-supplying industries. The following paragraphs describe the water supply situation for each county and the alternatives considered in evaluating the project benefit.

Coffee County--The Highland Rim Province, in which the Duck River originates, contains large ground water reserves. Even so, the cities of Manchester and Tullahoma, which will serve the future water supply needs of the people in this area, are finding it increasingly difficult to obtain a sustained flow of good quality water from springs or wells. Manchester already supplements its spring source with water from the Little Duck River and during extreme dry periods finds the quality of water from the spring so poor, due to unacceptable taste, that its use has to be discontinued. The low flow in the Little Duck River at the present Manchester intake is estimated as less than 3 cfs. The Manchester system now serves some 5000 people in the area who use an average of about 0.5 million gallons of water daily. The city's daily water requirement is expected to exceed 1 million gallons by 1975, with the expansion of its portion of the water grid throughout northern Coffee County. At present it does not serve any appreciable industries, but this picture should change with development of the water grid system and completion of Interstate 24.

The present source of water for the city of Tullahoma, at Short Springs, would have to be supplemented or replaced by 1975 according to city officials. Their records show that the minimum flow in the spring dropped from 6 mgd in 1941 to 4 mgd in 1961. Present water use within the city, which serves some 15,000 people, is approaching 2 mgd; but this does not take into consideration several large consumers who supplement their needs through

their own private wells. As with Manchester, future demands on the Tullahoma system will be affected by the water grid system and its closeness to Interstate 24. (Figure 10 shows an industrial park at Tullahoma.) The area which the city of Tullahoma will serve on the water grid system includes southern Coffee County and parts of northern Moore and Franklin Counties.

Normandy Reservoir would serve as an adequate source of water supply for the water grid system in Coffee County. As an alternative, the cities of Manchester and Tullahoma would either have to relocate their individual intakes or consider a new combined water plant on the reservoir somewhere between the two cities in order to serve the potable water needs of the area. Future requirements are expected to reach about 10 mgd by the year 2025 and over 20 mgd in 100 years. The least-cost alternative to Normandy Reservoir which would provide the water supply needs for Tullahoma and Manchester and the contiguous areas would be Tims Ford Reservoir, on the Elk River. The difference in the cost of the two cities going to Tims Ford Reservoir for their water supply as compared with obtaining this supply from Normandy Reservoir is the benefit attributable to the Normandy project.

Bedford County--The city of Shelbyville has the most desirable location in the upper Duck River Basin from the viewpoint of water supply. Although extremely low flows have occurred in the past at Shelbyville due to upstream regulation by a small hydro unit, now not in use, the minimum flow under present conditions is in the order of 45 cfs. This amount is sufficient to satisfy the foreseeable future needs. However, all of the natural flow would be needed to obtain desired water quality during low-flow periods, and the entire amount required for water supply during these periods would have to be withdrawn from storage in Normandy Reservoir.

The present average daily municipal water use in the area of Bedford County, served by the city of Shelbyville, is about 2 million gallons. The system now serves more than 10,000 people and includes a number of small industries (see figure 11). Based on population projections for Shelbyville and its contiguous area it is estimated that water requirements will rise to over 5 mgd by the year 2025 and about 7.5 mgd by 2075.

The least-cost alternative to Normandy Reservoir which would provide the needs at the city of Shelbyville and surrounding Bedford County would be an

Figure 10 - Industrial Park at Tullahoma, Tennessee

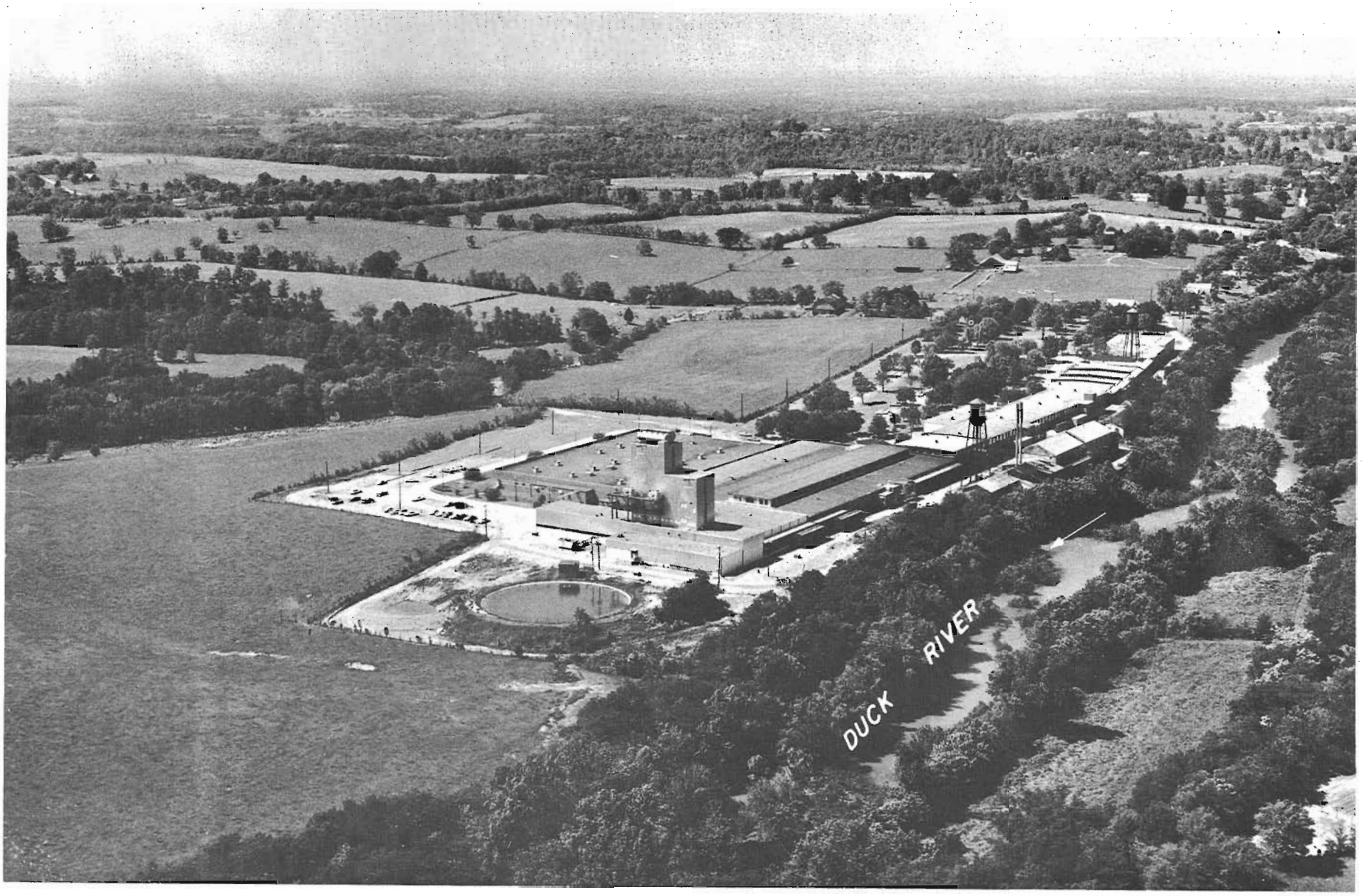

Figure 11 - Industry Along Duck River at Shelbyville, Tennessee

impoundment on a tributary watershed upstream from the city, which would store 4300 acre-feet for release during low-flow period.

Maury and Marshall Counties--In contrast to conditions at Shelbyville, the record 7-day low flow in the Duck River at Columbia was 7.7 cfs in 1931. This is probably indicative of natural flow conditions since observed low flows of fewer days' duration could have resulted from regulation by small, now abandoned, upstream power plants. This unusual low-flow condition is due in part to the shallow soils of relatively low permeability in the Nashville Basin, where there is little ground water reserve and the small streams become completely dry during dry periods.

In comparison to the low flow at Columbia, the present average daily municipal and rural use in Maury County is approaching 6 million gallons and daily withdrawals for processing and cooling water by self-supplying industries amount to about 29 million gallons.

The municipal water system of the city of Columbia, which now serves some 25,000 people, mostly within the city limits, will eventually supply all of Maury County with potable water through the water grid system. Projection of future water supply requirements, exclusive of major industrial use, indicate that by 2025 about 17 million gallons will be required to supply the daily needs of the people. By 2075 this water requirement can be expected to rise to some 28 mgd. The city's present intake station could be expanded to pump water released from Columbia Reservoir or a new station could be located at or above the dam to utilize the additional head provided by the reservoir.

The projection of water supplies which will be required for large water-using industries is difficult. The only fact assured is that industrial expansion will be at a minimum if an adequate supply of water is not available at the time it is needed. Most of the large water-using industries in Maury County recirculate their process water two or three times during low-flow periods. They obtain 90 percent of their supply from the Duck River and the remainder from several large tributary streams downstream from Columbia. Most of the industries on tributary streams have indicated that they will have to go to the Duck River for additional water for future expansion. This area is most attractive to large, heavy metalworking and chemical industries, which are heavy users of process

water. Future industrial growth, therefore, is heavily dependent upon the availability of large quantities of water. According to information furnished by the Middle Tennessee Industrial Development Association, several industrial prospects in the past few years would have considered sites around Columbia except for the fact that an adequate water supply was not available. Two recent prospects would have had an initial employment of 250 people and would have required almost 11 mgd for cooling and processing. Industrial sites such as the one at Alexander Bend, shown in figure 12, were available but water was not.

The phosphate industry in Maury County has not developed the additional processing operations which produce phosphoric acid and other phosphate products. A major deterrent has been the lack of adequate water supply. The Monsanto Chemical Company plant (figure 13) alone would require about 14 million gallons of additional water daily to make the conversion to phosphoric acid. Alleviation of the water problem should encourage the creation of secondary processing among the several major companies in the area as well as expansion of their existing elemental phosphate facilities.

In planning studies, it was determined that Columbia Reservoir should be operated so as to provide up to 150 cfs for water supply purposes by the year 2075. This would improve the water supply for present industry and encourage expansion, would cover the future requirements for the water grid system in Maury County, and should attract new industry to the county. The reservoir also would assure an adequate supply of water at the Lewisburg intake during dry months to serve the people and industry (figure 14) of that city. This would make it feasible to serve the future requirements of the water grid system in Marshall County which are expected to reach 4 mgd by 2025 and 7 mgd by 2075.

The entire amount required for water supply purposes in Maury County would be withdrawn from storage inasmuch as all natural inflow would be needed for water quality control during low-flow periods. The volume of storage required to provide the minimum continuous flow for water supply would be about 45,000 acre-feet. The alternative to Columbia Reservoir which would provide the water supply needs at the least cost would be impoundments in two tributary watersheds in the area. Each impoundment was planned to store 22,500 acre-feet, with one dam being constructed initially and a second one after 50 years to satisfy the increasing requirements.

Figure 12 - Alexander Bend Industrial Site At Columbia, Tennessee

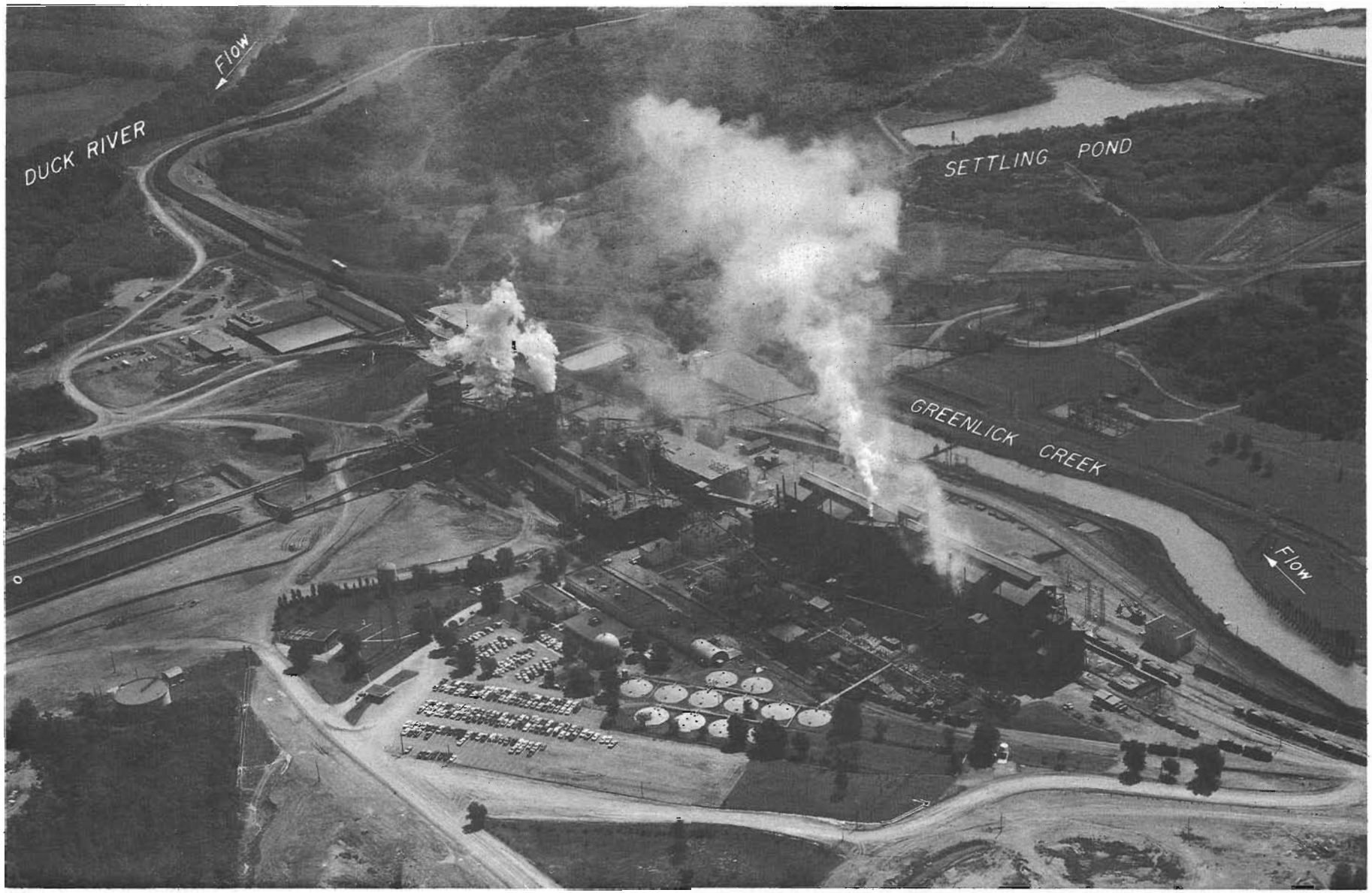

Figure 13 - Monsanto Chemical Company Plant near Columbia, Tennessee

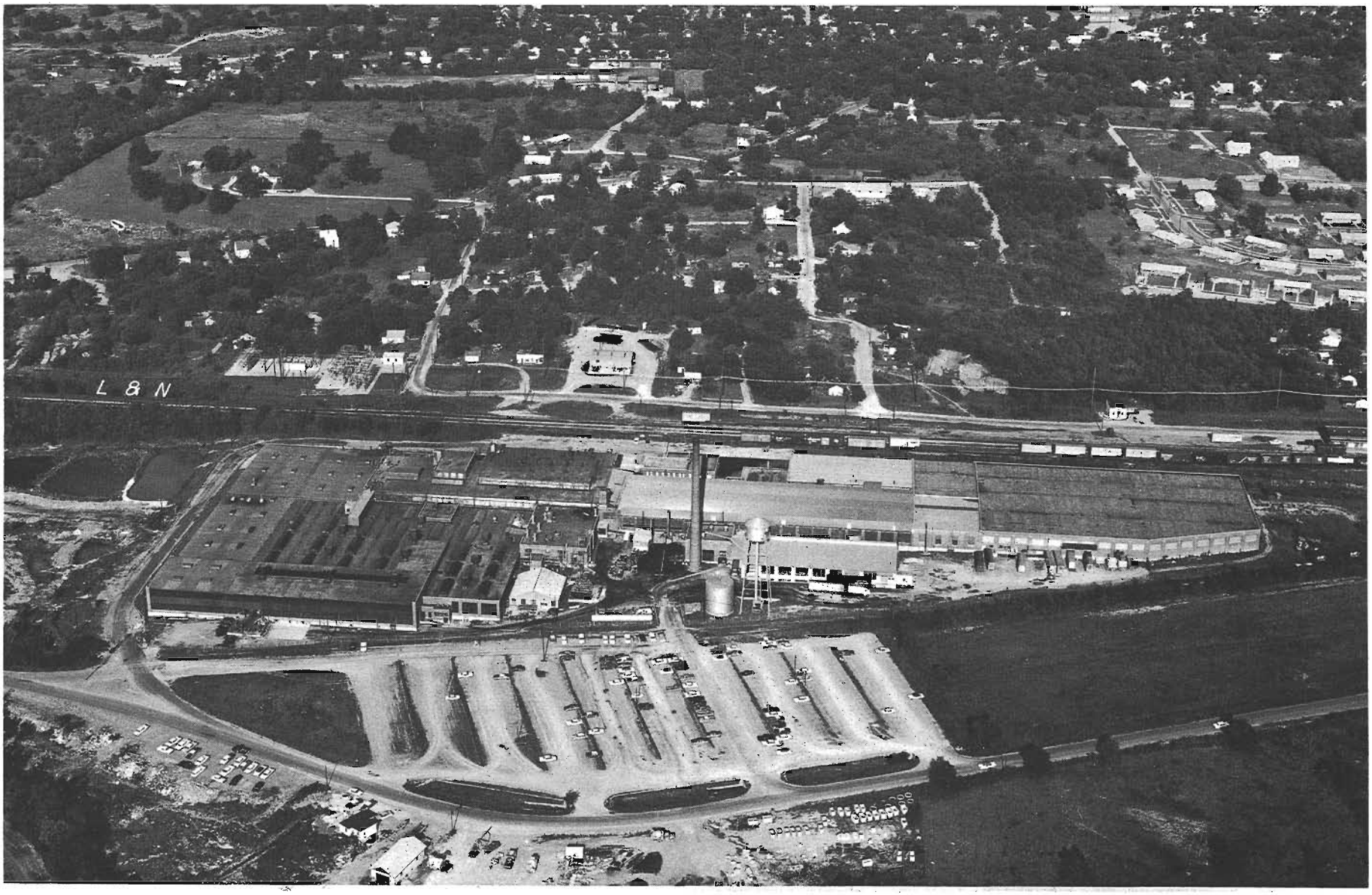

Figure 14 - Industrial Site at Lewisburg, Tennessee

The present worth of the total annual costs of the least-cost alternatives that would provide the water supply needs of the upper Duck River Basin would be $810,000.

Recreation

At present the upper Duck River watershed has no major impoundments to complement the area's existing natural and man-made recreation attractions. The Duck River project would provide opportunities for a variety of water-based recreation activities, thus enhancing the recreation appeal of the watershed and its future role in the region. Recreation and tourism should make a major contribution to the economy of the basin due to the improved resource base and the central location with respect to population centers and crossings of the area by Interstate Highways 65 and 24.

The setting for the Normandy impoundment, in an area varying from rolling pasturelands to sheer bluffs, would provide a variety of recreation experiences not currently available in the watershed and that would not be provided by the Columbia Reservoir. The several coves and lateral embayments would add to the attractiveness of Normandy Reservoir; it would have the characteristics of both a large lake and a river. While undevelopable for many uses because of its steepness, the shoreline would have clusters of strategically located developable lands and would offer a contrasting type of reservoir recreation. The upper one-third of the lake would provide an opportunity for boating and other recreation in a riverlike setting for up to 10 miles in length, and it would be easily accessible from Old Stone Fort Park. This stretch of narrow, winding lake would vary in width from the existing stream bed to 700 feet and would be banded by cliffs up to 200 feet high. A special effort would be made throughout the reach to protect the natural qualities of the shoreline. The lower two-thirds of the reservoir would provide opportunities for general reservoir recreation activities, including power boating and water skiing. This portion of Normandy Reservoir would offer rolling pasturelands, scenic hills, and high-bluff areas. and would have open expanses of water from 0.2 mile to 2.5 miles in length. Located along this portion of the reservoir are several key parcels of land suitable for development as access, day-use, and commercial areas, etc., without adversely affecting the overall scenic setting of the lake.

In contrast to the steep surrounding of Normandy Lake, Columbia Reservoir, in a setting of hilly to rolling topography with numerous lateral drainages, would be scenic and easily accessible. It would have a higher proportion of suitable shoreline for a wide variety of recreation developments. The impoundment would have wide and deep expanses of water, numerous coves and islands, and would have the characteristics of a winding river in its upper reaches.

In order to partially meet some of the anticipated initial needs for recreation use of the reservoirs and to assure adequate future public access to the lakes, provisions would be made for boating access and pertinent support facilities at strategic locations around the shorelines. These areas would provide picnic and campgrounds having sanitary facilities and potable water, in addition to paved ramps and parking. The construction of many of the facilities would be completed by the time the lakes are usable.

Both the Normandy and Columbia Reservoirs would have relatively stable pools during the primary recreation season, May 15 through October 15, with a maximum fluctuation of 5 feet in all except the driest years. The impoundments would complement and supplement the recreation opportunities existing or under construction in the watershed. Old Stone Fort State Park, scheduled for completion in 1977, will be located at the eastern end of the basin near Manchester. It will be developed around four distinct areas--historic, day-use, nature, and camping (figure 15). It is expected to receive 400,000 visits annually by 1977. Henry Horton State Park (figure 16), located north of Shelbyville, having an 18-hole golf course, 65-site campground, restaurant, swimming pool, rental cabins, and a motel, is expected to receive 680,000 visits by 1970. The park receives 96 percent of its total business from people outside the immediate area. Shelbyville hosts the Tennessee Walking Horse Celebration which attracts over 100,000 people annually.

The reservoir recreation demand for the project was estimated by using the Bureau of Outdoor Recreation 1965 participation rates for the east south-central census region for 11 selected activities. These activities include those reservoir-oriented or reservoir-related uses which are expected to be major determinants of the demand for reservoir recreation in the project market area. Of all the social and economic factors considered by the Bureau of Outdoor Recreation, per capita income was found to be the most significant determinant of participation rates.

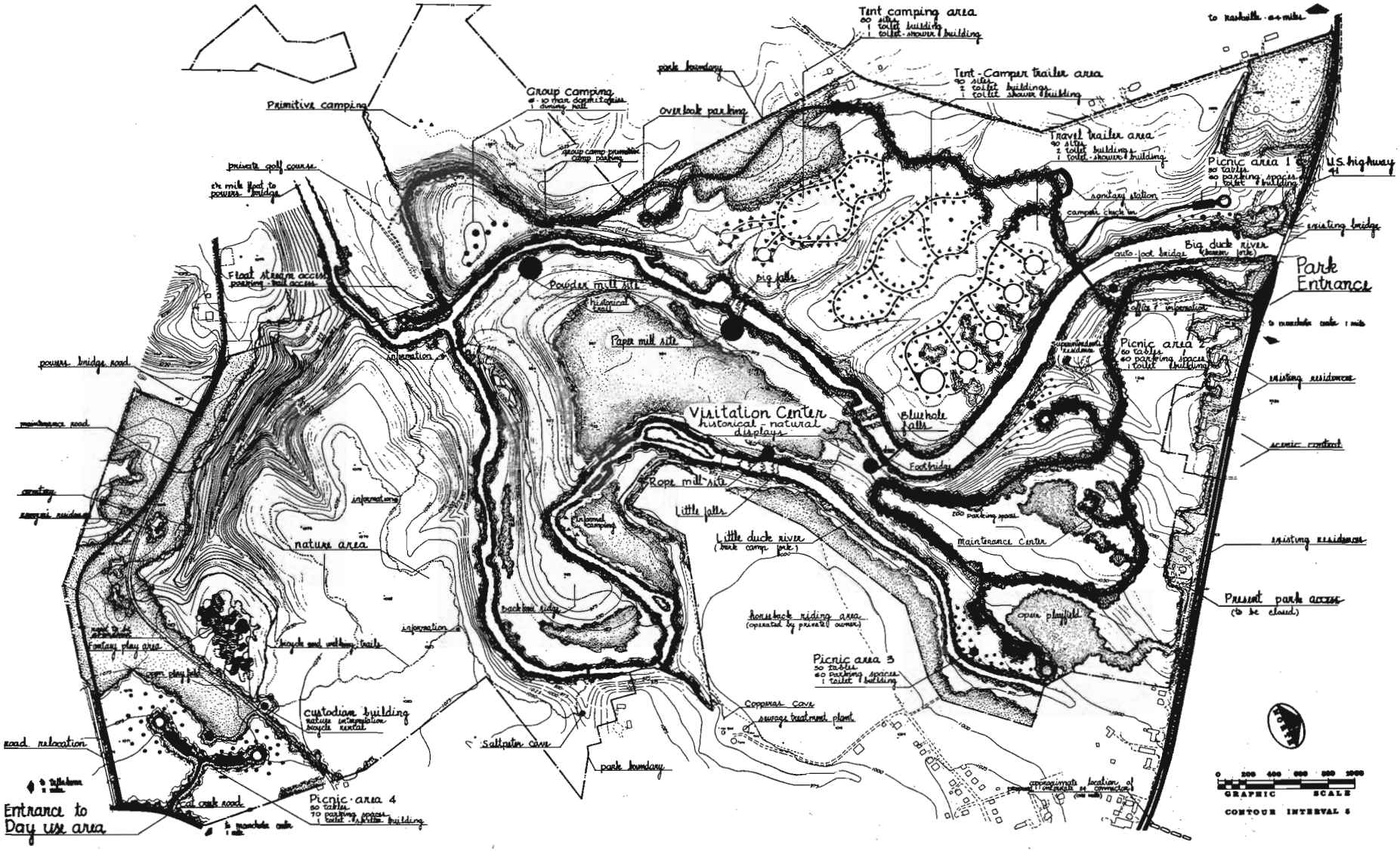

Figure 15 - **Master Plan, Old Stone Fort State Park**
(Courtesy of Tennessee Department of Conservation)

Figure 16 - Henry Horton State Park, Looking South

The demand estimates are adjusted for the difference in per capita income between the project market area and the east south-central census region. The local market area includes all those counties within a 1-hour drive of the project, but the primary local market is confined to the 13 counties within or immediately adjacent to the Duck River Basin.

The net recreation demand from the primary local market area is estimated at 64 percent of the total recreation demand for the Duck River project in 1980 and 70 percent in both 2000 and 2020. A larger regional market area, located between 1 and 3 hours' driving time from the project, was also utilized in the study. Although some use is expected to originate beyond a 3-hour drive, it was not determined in this study. The projected populations, 12 years and older, for these market areas are:

Year	Primary Local Area (13 Counties)	Regional and Remaining Local Area
1980	284,000	2,272,000
2000	366,000	3,090,000
2020	464,000	4,059,000

The following table summarizes pertinent recreation demand and supply estimates for the eleven selected recreation activities. The gross potential demand from the primary local market area is adjusted for the expected supply of recreation opportunities without the Duck River project. This has been done in two steps: (1) deducting the nonreservoir- and nonpark-oriented demand and (2) deducting that portion of demand which is expected to occur at alternative reservoirs and parks existing or presently under construction.

Projected Recreation Demand

	Visitation		
Primary Local Market Area	1980	2000	2020
Gross recreation demand	5,331,000	7,540,000	10,100,000
Supply without project	2,924,000	3,170,000	4,200,000
Net recreation demand, Duck R proj	2,407,000	4,370,000	5,900,000
Regional and Remaining Local Market Areas			
Gross recreation demand	146,426,000	203,460,000	273,000,000
Recreation demand, Duck R proj	1,340,000	1,840,000	2,500,000
Residual recreation demand	145,086,000	201,620,000	270,500,000
Total Recreation Demand, Duck R proj	3,747,000	6,210,000	8,400,000

Based on past experience at similar projects, the recreational usage of the two reservoirs comprising the Duck River project, excluding hunting and fishing, is estimated to be 1,065,000, 1,450,000, and 1,470,000 in 1980, 2000, and 2020 respectively. Since the projected demand for reservoir-oriented activities is considerably larger than this usage, it is evident that the recreation potential of the Duck River project will be fully utilized but can supply only part of the expected demand. Using $1 per recreation-day as the applicable value for day-use areas when certain minimum facilities are added, and converting these values to present worth, the average annual benefit would be an estimated $1,275,000.

The recreation potential of Columbia and Normandy Reservoirs would have a complementary and supplemental recreation resource in the reach of the river between the two lakes. Of this portion, a 15-mile stretch from Normandy Dam site to the U. S. 41A crossing of the Duck River probably would have the best qualities as a pastoral scenic stream, although the stream's potential is still under study. This unusually winding reach of the river has a variety of islands, fords, quiet pastoral scenes, bluffs, and stretches of quiet pools and riffles. The stream would offer an opportunity for a variety of recreation uses including float trips. Other prospective activities would be picnicking, hiking, nature study, photography, fishing, and scenic enjoyment. This portion of the river during dry periods would require some low-flow augmentation. Releases from Normandy Reservoir would assure adequate float-stream conditions during the recreation season. To assure the availability of this area for public use, the shoreline of the river should be protected through purchase and scenic easement. The costs and benefits associated with this scenic stream portion have not been included in the project evaluation. Further studies are under way to determine its relationship to the overall project.

Fish and Wildlife

The fish and wildlife aspects of the Duck River project have been coordinated with the Tennessee Game and Fish Commission at all stages of study. The commission has been asked to furnish data on fish and wildlife resources and has given recommendations concerning the effects of this project on existing and expected populations and habitat.

The proposed lakes, with a total surface area of almost 16,000 acres at full pool, would offer attractive boat and bank fishing opportunities. Based on experience

with other reservoirs and expected average monthly water levels, it is estimated that the annual fisherman-use would be about 117,000 fishing trips the first year. The present stream-fishing use in the project areas is estimated to be about 31,000 trips annually. Thus, the net increase in initial use of the reservoirs would amount to about 86,000 trips. Such use could be expected to increase at about 3 percent per year for the first 10 years, 1-1/2 percent per year for the next 15 years, and level off thereafter. Using $1 per fishing trip and converting these totals to present worth, the average annual fishing benefit attributable to the reservoirs would be $135,000.

A 3.5-mile reach of the Duck River from the Normandy Dam site downstream to Cortner Mill Dam has a good potential for development of trout fishing. Land costs for several access points in this reach have been included in the project cost. Temperature studies indicate the possibility of extending this fishery several miles downstream. However, the prediction of stream temperatures is not sufficiently advanced to set this limit. After the dam is constructed, these temperatures can be measured over a period of time and the limit established.

Low-level releases from the reservoir, through the Howell-Bunger valve provided for low-flow augmentation, should provide the proper habitat for trout except that an additional high-level auxiliary slide gate is considered necessary so that excess reservoir releases during late spring and summer floods can be made from water of high-oxygen content near the surface of the reservoir. It is estimated that the annual fisherman-use downstream from the dam would be increased by almost 6,000 trips, valued at $2 net per fishing trip. This would give an annual benefit of $12,000 for trout fishing.

A warm water fishery could be developed below Columbia Dam since increased minimum flows would reduce siltation and decrease both domestic and industrial pollution. The expected increase in annual fisherman-use would be about 100 trips per mile for 100 miles, or 10,000 trips, valued at $1 net per trip. The average annual warm water fishing benefit would, therefore, be $10,000.

It would be possible to develop an excellent waterfowl refuge and hunting area around Cedar Creek which would be managed primarily for geese. Among the prospective waterfowl, the Canadian goose stands foremost as the trophy species. Only two areas in Tennessee now offer reasonable opportunity to observe and hunt geese. One of these, near Dayton, Tennessee, demonstrates the present inequality between supply and demand since two out of every three hunters who apply for

reservations must be turned away. A well-developed goose management area at Cedar Creek, which is located on a major migration route, could do much to alleviate the deficiency. The increased interest in conservation education, preservation of open space, and outdoor hobbies points to an increased need to furnish suitable hunting facilities near urban centers. The Cedar Creek waterfowl area would help fulfill these interests. The State Game and Fish Commission has expressed both an interest in the waterfowl area and its intention to participate in the development.

The cost of additional land required for the refuge and management area as well as the cost of a dam near the mouth of Cedar Creek, which would form a permanent pool of 315 acres at elevation 630.5, have been included in the cost estimate for the Duck River project. The impoundment would be essential to the goose management program. The location of the Cedar Creek waterfowl unit is shown on exhibit 11.

Although no goose hunting could be allowed during the first 5 years, in order to permit the birds to build a stable wintering population, some 3,000 man-days of hunting could be supported about the sixth year. After 10 years, this use could be expected to increase to 4,000 man-days annually. Incidental to goose hunting, 3,000 man-days of dove hunting could be furnished annually, beginning with the first year of operation. The lake formed for waterfowl also would have added benefits for managed fishing. It should supply about 10,300 trips annually the first 5 years, increasing to about 20,000 trips annually thereafter. Assigning net values to these various trips of $3 for dove hunting, $6 for goose hunting, and $1 for fishing, and converting them to present worth, the average annual benefit would be $42,000 for hunting and $20,000 for fishing.

The present open and woodland area to be inundated by the reservoirs supports a sizable population of quail, rabbit, squirrel, raccoon, and deer. The Tennessee Game and Fish Commission estimates upland and forest game losses, both from reduced habitat and animals, would result in an annual wildlife loss amounting to about $19,000.

The acquisition of approximately 3,000 additional acres of land lying between the state-owned Bedford Lake and Normandy Reservoir would be ideal as a wildlife management and public hunting area. This land, under development and management for public hunting and wildlife and nature observations by the Tennessee Game and Fish Commission, would provide many benefits both local and regional.

However, when the estimated cost of the land is compared with the benefits as presently evaluated, the benefit-cost ratio is not favorable. Therefore, this land has not been included as part of the Duck River project in this report. Further studies will be made of the area to see if its offsetting cost to wildlife losses and its net benefits for future use might justify its inclusion in the project.

The total average annual fish and wildlife benefit associated with the Duck River project is summarized as follows:

Reservoir	
Fishing	$135,000
Hunting and habitat loss	-19,000
Tailwater	
Trout fishing	12,000
Warm water fishing	10,000
Cedar Creek	
Hunting	42,000
Managed fishing	20,000
Total average annual benefit	$200,000

Transportation Savings

Highway relocations in conjunction with Normandy and Columbia Reservoirs would result in improvement in grade or alignment of many of the existing travel routes. The resultant transportation savings have been measured in terms of the reduction in road-user costs and the value of other benefits brought about by the improvements. The estimated average annual value of these savings is $50,000.

Redevelopment and Expansion

Past growth in the economy of the 4-county upper Duck River valley has been less than its potential growth. The area has good industrial possibilities but in recent years the growth rate in manufacturing has declined. The labor force of the four counties was some 42,000 in 1960 according to the Census of Population. Of this number, 4.5 percent were unemployed and actively seeking work. Estimates made in 1964 suggest an increase in total employment but also some increase in unemployment. This condition is due to the faster rate at which the labor force is increasing as compared with the rate of increase in number of jobs.

Jobs in agriculture declined between 1950 and 1960 and will decline further, but the proportion of the labor force working on farms is still larger here than elsewhere in the state or in the nation. The increase in employment in the 4-county area from 1950 to 1960 was due mainly to the gain in women workers. In fact, the number of women reporting employment was 3144 greater in 1960; whereas, the number of men employed decreased by 629. The greater part of this change can be explained by the decrease in the number of men engaged in farm work. Because of the lack of employment opportunity there is a tendency for the young people to leave the area to find jobs. The future growth rates in population and employment will depend on the nonfarm job opportunities within the area and nearby counties.

Construction of the proposed Duck River project would result in redevelopment benefits, which are defined as the use of unemployed or underemployed resources in construction and, subsequently, the operation and maintenance of the project. In addition, the increased economic activity made possible by the project, measured in terms of the utilization of the unemployed or underemployed, is classified as expansion benefits. These benefits, which are described in the following paragraphs, are estimated from a national viewpoint. The national viewpoint takes into account only the net increase in productivity to the nation as a whole as compared with the regional viewpoint which would include benefits derived from resources transferred from one area to another at no gain to the nation.

Redevelopment--The construction, operation, and maintenance of the Duck River project would provide employment to some of the otherwise subemployed labor in the area. Based on an analysis of employment applications and other data from the area as compared with prospective employment required for the project, it is estimated that $1,700,000 of the $23,000,000 of project wages would represent the fuller employment of the otherwise subemployed. The equivalent annual value of this redevelopment benefit, when spread over the 100-year project economic life, is $80,000.

Expansion--A larger and longer lasting benefit from more productive use of subemployed labor in the region would be provided by the creation of more jobs in industrial and related trades and services employment. The industrial growth would occur on sites located downstream from the dams which would be benefited primarily by an assured water supply of high quality and also by increased flood

protection. Lack of availability of these project services is currently a limiting factor to industrial development. Analyses indicate that after the project is built, high-wage industries with an employment of about 3000 and an annual payroll of more than $22,000,000 (1966 wage level) could be expected to locate on these waterfront sites. An equal number of trades and services jobs would follow from the increased industrial employment and would have a payroll approaching $15,000,000. In the analyses, nine types of manufacturing industries were identified which would be oriented to the sites and conditions created by the Duck River project. The selected industries would be medium or large users of raw water, would have annual wages per employee above the average for Tennessee, and would have available markets in the Southeast. They were chosen from the group showing rapid growth in the past few years. The number of employees, skill requirements, and wages for an average-size plant in these industries were assumed in estimating the employment and wage impact of the anticipated industrial growth. Other analyses of associated increases in trades and services employment and wages were based on observed relationships for the Southeast. The combined increases in industrial and trades and services jobs and wages are expected to occur on the approximate time schedule given below:

Years After Project Construction	Numbers of Jobs	Annual Wages (1966 Level)
5	800	$ 4,700,000
15	2000	12,000,000
25	3000	19,500,000
50	6000	37,000,000

The expansion benefit from more productive use of the subemployed in these new jobs is estimated by (1) eliminating from the benefit computations those categories of jobs which have skill requirements that would keep them from being filled from the subemployed labor force and (2) crediting for the remaining jobs the difference between wages to be paid and an average alternative wage of $3300 per annum. The resulting expansion benefit, based on 1966 wages, is then escalated at 4 percent per year to 1972 for comparability with project costs, which are also projected to that time. The creditable share of wages is thus estimated to increase from $1,000,000 in 5 years to $5,000,000 in 25 years after project construction. Credit is not taken after 25 years, because plants would become obsolete by that

time and also because subemployment is projected to decrease by that time even without the project. These expansion benefits are discounted for the buildup period and credited to the project only in proportion to the project's share of the public investments considered necessary to accommodate the new jobs. On this basis, the expansion benefit has an equivalent annual value of $1,445,000 over the economic life of the project.

The project would have considerably more impact on a regional basis than is shown by the national expansion benefits. Workers employed in jobs which would be generated as a direct result of the construction of the Duck River project would be earning almost $24,000,000 annually within 25 years after project construction. The region would benefit by the full impact of this amount, although only $5,000,000 of this sum is claimed as a national benefit.

ECONOMIC ANALYSIS

The estimated cost for economic analysis of the Duck River project, including an allowance of $5,500,000 for interest during construction, is $79,000,000. Interest has been computed at a rate of 4-5/8 percent; and the investment, exclusive of reservoir land, has been amortized over the 100-year economic life of the project.

Computed annual charges and estimated annual benefits are tabulated below:

Annual Costs	
Interest and amortization	$3,685,000
Operation and maintenance, including replacements	365,000
Total Annual Costs	$4,050,000
Annual Benefits	
Flood control - System	$ 180,000
- Local	185,000
Water supply	810,000
Water quality control	365,000
Recreation	1,275,000
Shoreline development	370,000
Fish and wildlife	200,000
Transportation savings	50,000
Redevelopment	80,000
Expansion	1,445,000
Total Annual Benefits	$4,960,000
Benefit-Cost Ratio	1.2:1.0

Allocation of Project Cost

A tentative allocation of the project construction cost is shown in the following tabulation. The direct investment for flood control was determined by taking the difference between the cost of the multiple-purpose project, as planned, and the cost of a project at the same site with flood storage eliminated from the reservoir. The direct investment for the other project purposes was determined by identifying the cost of the particular item or items that serve only the individual purpose. The cost of land in the recreation and wildlife management and refuge areas has been assigned to recreation and fish and wildlife respectively. Estimated justifiable expenditures are capitalized net benefits (less operation and maintenance) limited to alternative costs, including for all purposes except redevelopment, a prorated amount for project-induced expansion benefits. In the case of the reservoir access areas and entrance roads the operation and maintenance cost has been assigned to recreation. The remaining common operation and maintenance cost has been divided proportionally among flood control, water supply, water quality control, recreation, and fish and wildlife.

Tentative Allocation of Construction Cost

Purpose	Estimated Justifiable Expenditure	Direct Investment	Remaining Justifiable Expenditure	Allocation of Common Cost	Total Estimated Multiple-Purpose Investment Amount	%
Flood control	$ 9,460,000	$ 4,800,000	$ 4,660,000	$ 4,371,000	$ 9,171,000	12.5
Water supply	16,147,000	226,000	15,921,000	14,932,000	15,158,000	20.6
Water quality cont	7,250,000	509,000	6,741,000	6,322,000	6,831,000	9.3
Recreation	27,551,000	7,610,000	19,941,000	18,702,000	26,312,000	35.8
Shoreline develop	9,370,000	-	9,370,000	8,788,000	8,788,000	12.0
Fish and wildlife	4,718,000	1,764,000	2,954,000	2,770,000	4,534,000	6.2
Transp savings	1,215,000	-	1,215,000	1,140,000	1,140,000	1.5
Redevelopment	1,670,000	-	1,670,000	1,566,000	1,566,000	2.1
Total	$77,381,000	$14,909,000	$62,472,000	$58,591,000	$73,500,000	100.0

APPENDIXES

Tennessee Valley Authority
Division of Water Control Planning
Project Planning Branch

APPENDIX A

SUMMARY OF PRINCIPAL FEATURES

Knoxville, Tennessee
September 1968

APPENDIX A

SUMMARY OF PRINCIPAL FEATURES

DUCK RIVER PROJECT

NORMANDY DAM AND RESERVOIR

Location of Dam

On the Duck River at mile 248.6, in Bedford and Coffee Counties, Tennessee; about 1.5 miles upstream from the community of Normandy and 8 miles north of Tullahoma, Tennessee. It is 12 miles east of Shelbyville, Tennessee.

Access

A new secondary road would pass just downstream from the dam site and connect with existing roads to Tullahoma and Normandy. U. S. 41A serves Tullahoma, I-24 and U. S. 41 serve Manchester, and Tennessee State Highway 55 connects these two cities.

A railhead, served by the Louisville and Nashville railroad, is located at Normandy.

Drainage Area Above Dam Site	195 sq miles
Streamflow	
Maximum probable flood at dam site	69,000 cfs
Average flow at dam site (33 years)	320 cfs
Maximum known flood (1902) at gage near Shelbyville	87,000 cfs
Minimum flow at gage near Shelbyville:	
1-Day flow (1945)	approx 20 cfs
7-Day flow (1941)	approx 45 cfs
Reservoir	
Counties affected	Bedford and Coffee
Operating levels at dam:	
Maximum pool (top of spillway gates)	El. 880
Normal maximum	El. 875
Normal minimum	El. 859
Length at El. 875	17 miles
Length of shoreline at El. 875 - Main shore	70 miles
- Islands	2 miles
Area to be cleared	approx 500 ac
Volume (flat-pool assumption):	
Total at El. 880 (area = 3,460 ac)	134,000 ac-ft
Total at El. 875 (area = 3,230 ac)	117,000 ac-ft
Total at El. 859 (area = 2,490 ac)	72,000 ac-ft
Minimum controlled flood storage:	
January 1 - 6 inches (El. 880 - El. 859)	62,400 ac-ft
April 1 - 4 inches (El. 880 - El. 867)	41,600 ac-ft
May 15 - 1.6 inches (El. 880 - El. 875)	17,000 ac-ft

Tailwater
Maximum probable flood . . . . . approx El. 823

Dam
Type . . . . . impervious earth fill
Total length along baseline (incl spillway) . . . . . 2,807 ft
Maximum height above natural ground . . . . . 110 ft
Top of dam . . . . . El. 895
Spillway:
Material and type . . . . . concrete weir and chute
Crest level . . . . . El. 840
Crest length (clear) . . . . . 80 ft
Crest control . . . . . two radial gates, each 40 ft high by 36 ft wide
Top of gates . . . . . El. 880
Operation . . . . . fixed hoists remotely controlled from Pulaski, Tenn.
Discharge capacity at El. 880 . . . . . 71,000 cfs
Auxiliary gates - Function . . . . . discharge surface flows
- Location . . . . . in upper part of radial gates
- Number and size . . . . . two, each 6 ft by 8 ft
- Discharge capacity at El. 875 . . . . . approx 1,050 cfs
Sluiceway:
Size and type . . . . . one 36-inch-diam pipe embedded in center spillway pier
Regulating valve . . . . . one 36-inch-diam Howell-Bunger
Discharge capacity at El. 859 . . . . . approx 250 cfs

Estimated Major Construction Quantities
Earth excavation . . . . . 180,000 cu yd
Earth fill . . . . . 1,800,000 cu yd
Rock excavation . . . . . 170,000 cu yd
Concrete . . . . . 30,000 cu yd

COLUMBIA DAM AND RESERVOIR

Location of Dam
On Duck River at mile 136.9, in Maury County, Tennessee; 2 miles due east of Columbia, Tennessee.

Access
A secondary road leading east from Columbia crosses the Duck River about 2,000 feet below the dam site. Several primary roads, notably U.S. 31 and Tennessee State Highway 50, pass through Columbia. I-65 crosses the reservoir at Duck River mile 151.

A railhead, served by the Louisville and Nashville railroad, is located at Columbia.

Drainage Area - Total above dam site . . . . . 1,181 sq miles
- Uncontrolled (below Normandy Dam) . . . . . 986 sq miles

Streamflow

Maximum probable flood at dam site	170,000 cfs
Maximum known flood at Columbia (1948)	61,100 cfs
Average flow at dam site (50 years)	1,870 cfs
Minimum flow at Columbia gage:	
1-Day flow (1927)	approx 2.6 cfs
7-Day flow (1931)	approx 7.7 cfs

Reservoir

Counties affected	Maury and Marshall
Operating levels at dam:	
Maximum pool (top of spillway gates)	El. 635
Normal maximum	El. 630
Normal minimum	El. 603
Length at El. 630	54 miles
Length of shoreline at El. 630 - Main shore	221 miles
- Islands	15 miles
Area to be cleared	approx 1,700 ac
Volume (flat-pool assumption):	
Total at El. 635 (area = 15,000 ac)	363,000 ac-ft
Total at El. 630 (area = 12,600 ac)	294,000 ac-ft
Total at El. 603 (area = 4,300 ac)	80,000 ac-ft
Minimum controlled flood storage:	
January 1 - February 1 - 5.4 inches (El. 635 - El. 603)	281,000 ac-ft[a]
April 1 - 3.6 inches (El. 635 - El. 618.5)	187,000 ac-ft[a]
May 15 - 1.3 inches (El. 635 - El. 630)	69,000 ac-ft

Tailwater

Maximum probable flood	approx El. 617

Dam

Type	impervious earth fill
Total length along baseline (incl spillway)	2,325 ft
Maximum height above natural ground	105 ft
Top of dam	El. 645
Spillway:	
Material and type	concrete weir and chute
Crest level	El. 595
Crest length (clear)	200 ft
Crest control	five radial gates, each ~~40~~ 41 ft high by 40 ft wide
Top of gates	El. 635
Operation	fixed hoists remotely controlled from Pulaski, Tenn.
Discharge capacity at El. 635	200,000 cfs

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a. Excludes Cedar Creek impoundment.

Sluiceway:
Size and type . . . . . two 36-inch-diam pipes, embedded in center spillway piers
Regulating valves . . . . . two 36-inch-diam Howell-Bunger
Discharge capacity at El. 603 . . . . . approx 400 cfs

Estimated Major Construction Quantities
Earth excavation . . . . . 480,000 cu yd
Earth fill . . . . . 1,110,000 cu yd
Rock excavation . . . . . 340,000 cu yd
Concrete . . . . . 40,000 cu yd

CEDAR CREEK WATERFOWL REFUGE

Location
The dam would be located about 1 mile upstream from the mouth of Cedar Creek. The confluence of Cedar Creek with the Duck River is near mile 155.4.

Areas
Drainage area . . . . . 18 sq miles
Total waterfowl unit . . . . . 2,360 ac

Pool at El. 630.5
Length of shoreline . . . . . 5 miles
Area . . . . . 315 ac
Volume . . . . . 2,250 ac-ft

Dam
Type . . . . . impervious earth and rock fill
Total length (incl spillway) . . . . . 1,300 ft
Maximum height above natural ground . . . . . 28 ft
Top of dam . . . . . El. 635

Spillway
Material and type . . . . . concrete weir, chute excavated in rock
Crest level . . . . . El. 630.5
Crest width . . . . . 50 ft
Discharge capacity at El. 635 . . . . . 2,000 cfs

DUCK RIVER PROJECT

Benefits
Flood control, water supply, water quality control, recreation, fish and wildlife, shoreline development, improved highway travel, redevelopment, and expansion.

Estimated Time of Construction . . . . . 54 months

Estimated Total Cost $73,500,000

Tennessee Valley Authority
Division of Water Control Planning
Project Planning Branch

APPENDIX B

DETAILED COST ESTIMATE

Knoxville, Tennessee
September 1968

DUCK RIVER PROJECT
DETAILED ESTIMATE OF COST

NORMANDY UNIT

Account Number	Item	Quantity	Unit +	Price	Amount	Total
20	LAND AND LAND RIGHTS					
200	PURCHASE PRICE OF LAND	9,226	acre	$ 486.00	$4,488,000	
201	EXPENSE OF LAND AND PRIVILEGE ACQUISITION		L.S.		279,000	
204	RELOCATING HIGHWAYS AND HIGHWAY BRIDGES		L.S.		3,620,000	
207	RELOCATING AND PROTECTING OTHER STRUCTURES AND IMPROVEMENTS		L.S.		503,000	
	TOTAL LAND AND LAND RIGHTS					$ 8,890,000
21	STRUCTURES AND IMPROVEMENTS					
212	GENERAL YARD IMPROVEMENTS		L.S.		460,000	
216	MISCELLANEOUS BUILDINGS		L.S.		100,000	
	TOTAL STRUCTURES AND IMPROVEMENTS					560,000
22	RESERVOIRS, DAMS, AND WATERWAYS					
220	RESERVOIR					
-0	Clearing	500	acre	650.00	325,000	
-1	Engineering		L.S.		37,000	
	TOTAL RESERVOIR				362,000	
221	CONCRETE DAM AND SPILLWAY					
-2	Excavation and backfill					
-20	Clearing and grubbing	5	acre	650.00	3,000	
-22	Excavation - Earth	77,845	cu yd	0.40	31,000	
-23	- Rock	160,451	cu yd	3.30	529,000	
	Total excavation and backfill				563,000	
-4	Concrete					
-40	Overflow mass	7,193	cu yd	30.00	216,000	
-42	Spillway piers	3,150	cu yd	65.00	205,000	
-43	Spillway operating bridge	83	cu yd	175.00	15,000	
-44	Spillway training walls	567	cu yd	50.00	28,000	
-45	Spillway retaining walls	15,257	cu yd	31.00	471,000	
-46	Spillway chute floor slab	3,079	cu yd	40.00	123,000	
	Total concrete				1,058,000	
-5	Joints, stops, waterproofing, and drains		L.S.		29,000	
-6	Gates and appurtenances					
-61	Crest gates (radial)					
-610	Gate frames and guides	65	ton	1,000.00	65,000	
-611	Gates and seals	190	ton	1,000.00	190,000	
-612	Operating equipment		L.S.		100,000	
-66	Slide gates	2	each	1,100.00	22,000	#56,000
	Total gates and appurtenances				377,000	
-7	Auxiliary structures and equipment					
-72	Structural steel - Spillway operating bridge	59	ton	650.00	38,000	
-74	Miscellaneous metalwork		L.S.		10,000	
-75	Handrailing	214	lin ft	12.00	3,000	
-77	Pressure and other measuring devices		L.S.		5,000	
	Total auxiliary structures and equipment				56,000	
-9	Electrical work		L.S.		95,000	
	TOTAL CONCRETE DAM AND SPILLWAY				2,178,000	
223	EARTH OR EARTH AND ROCKFILL DAMS					
-1	Diversion and care of water		L.S.		335,000	
-2	Excavation and backfill					
-20	Clearing and grubbing	30	acre	650.00	20,000	
-21	Stripping	82,696	cu yd	0.75	62,000	
-22	Excavation - Earth	22,422	cu yd	1.00	22,000	
-23	- Rock	6,900	cu yd	10.00	69,000	
-28	Backfilling	29,432	cu yd	2.00	59,000	
	Total excavation and backfill				232,000	
-3	Foundation preparation and treatment		L.S.		275,000	
-5	Permanent drainage	20,676	cu yd	5.00	103,000	
-6	Earthfill					
-61	Rolled fill					
-610	From borrow	1,664,815	cu yd	0.80	1,332,000	
-8	Slope protection					
-80	Gravel blanket	17,855	cu yd	4.00	71,000	
-81	Riprap (from spillway stockpile)	53,562	cu yd	1.00	54,000	
-83	Seeding and sodding	80,933	sq yd	0.35	28,000	
	Total slope protection				153,000	
	TOTAL EARTH OR EARTH AND ROCKFILL DAMS				2,430,000	

Account Number	Item	Quantity	Unit	Price	Amount	Total
224	SLUICEWAYS					
-3	Conduit liners	4.4	ton	$1,000.00	$ 4,000	
-6	Water regulating equipment					
-60	Gates and appurtenances					
-600	Gate frames and guides	0.5	ton	1,000.00	1,000	
-601	Gates and seals	1	each	4,000.00	4,000	
-602	Operating equipment		L.S.		5,000	
-61	Main valves and operating equipment		L.S.		28,000	
-62	Trashracks	0.5	ton	1,000.00	1,000	
-63	Bulkheads		L.S.		5,000	
	Total water regulating equipment				44,000	
-9	Electrical work		L.S.		5,000	
	TOTAL SLUICEWAYS				53,000	
	TOTAL RESERVOIRS, DAMS, AND WATERWAYS					$ 5,023,000
26	ROADS, RAILROADS, AND BRIDGES					
260	ACCESS ROADS FOR PERMANENT USE		L.S.		520,000	
	TOTAL ROADS, RAILROADS, AND BRIDGES					520,000
27	VILLAGE AND RESERVOIR FACILITIES					
271	VECTOR CONTROL FACILITIES		L.S.		15,000	
272	PUBLIC USE FACILITIES		L.S.		900,000	
	TOTAL VILLAGE AND RESERVOIR FACILITIES					915,000
	TOTAL DIRECT COST - NORMANDY UNIT					$15,908,000

COLUMBIA UNIT

20	LAND AND LAND RIGHTS					
200	PURCHASE PRICE OF LAND	30,500	acre	varies	$11,660,000	
201	EXPENSE OF LAND AND PRIVILEGE ACQUISITION		L.S.		935,000	
204	RELOCATING HIGHWAYS AND HIGHWAY BRIDGES		L.S.		9,159,000	
205	RELOCATING RAILWAYS AND RAILWAY BRIDGES		L.S.		35,000	
207	RELOCATING AND PROTECTING OTHER STRUCTURES AND IMPROVEMENTS		L.S.		2,615,000	
	TOTAL LAND AND LAND RIGHTS					$24,404,000
21	STRUCTURES AND IMPROVEMENTS					
212	GENERAL YARD IMPROVEMENTS		L.S.		250,000	
216	MISCELLANEOUS BUILDINGS		L.S.		260,000	
	TOTAL STRUCTURES AND IMPROVEMENTS					510,000
22	RESERVOIRS, DAMS, AND WATERWAYS					
220	RESERVOIR					
-0	Clearing	1,715	acre	$ 650.00	1,115,000	
-1	Engineering		L.S.		90,000	
-8	Rim treatment		L.S.		125,000	
-9	Remove existing dams and bridges		L.S.		260,000	
	TOTAL RESERVOIR				1,590,000	
221	CONCRETE SPILLWAY					
-2	Excavation and backfill					
-22	Excavation - Earth	373,200	cu yd	0.40	149,000	
-23	- Rock	326,700	cu yd	3.00	980,000	
-28	Backfilling	11,800	cu yd	2.00	24,000	
	Total excavation and backfill				1,153,000	
-4	Concrete					
-40	Overflow mass	17,000	cu yd	27.00	460,000	
-42	Spillway piers	5,038	cu yd	65.00	327,000	
-43	Spillway operating bridge	170	cu yd	150.00	26,000	
-44	Spillway training walls	1,244	cu yd	50.00	62,000	
-45	Spillway retaining walls	7,000	cu yd	38.00	266,000	
-46	Spillway chute floor slab	7,156	cu yd	50.00	358,000	
	Total concrete				1,499,000	
-5	Joints, stops, waterproofing, and drains				38,000	
-6	Gates and appurtenances					
-61	Crest gates					
-610	Gate frames and guides	162	ton	900.00	146,000	
-611	Gates and seals	462	ton	1,000.00	462,000	
-612	Operating equipment		L.S.		250,000	
	Total gates and appurtenances				858,000	
-7	Auxiliary structures and equipment					
-72	Structural steel - Spillway operating bridge	126	ton	650.00	82,000	
-74	Miscellaneous metalwork		L.S.		25,000	
-75	Handrailing	500	lin ft	12.00	6,000	
-77	Pressure and other measuring devices		L.S.		5,000	
	Total auxiliary structures and equipment				118,000	
-9	Electrical work		L.S.		120,000	
	TOTAL CONCRETE SPILLWAY				3,786,000	

Account Number	Item	Quantity	Unit	Price	Amount	Total
222	AUXILIARY DAMS					
-1	Diversion and care of water		L.S.		33,000	
-2	Excavation and backfill					
-22	Excavation - Earth	11,800	cu yd	0.85	10,000	
	- Rock	3,400	cu yd	7.00	24,000	
	Total excavation and backfill				34,000	
-3	Foundation preparation and treatment		L.S.		63,000	
-4	Concrete (spillway)					
-40	Overflow mass	170	cu yd	35.00	6,000	
-44	Training walls	130	cu yd	150.00	20,000	
	Total concrete				26,000	
-6	Earth fill					
-61	Rolled fill					
-610	From borrow and excavation	33,400	cu yd	0.96	32,000	
-8	Slope protection					
-80	Gravel blanket	8,200	cu yd	3.00	25,000	
-81	Riprap	12,300	cu yd	3.00	37,000	
	Total slope protection				62,000	
	TOTAL AUXILIARY DAMS				250,000	
223	EARTH DAM					
-1	Diversion and care of water		L.S.		$ 500,000	
-2	Excavation and backfill					
-20	Clearing and grubbing	20	acre	$ 650.00	13,000	
-21	Stripping	62,000	cu yd	0.75	47,000	
-22	Excavation - Earth	47,800	cu yd	1.00	48,000	
-23	- Rock	9,800	cu yd	7.00	69,000	
	Total excavation and backfill				177,000	
-3	Foundation preparation and treatment		L.S.		170,000	
-5	Permanent drainage	14,000	cu yd	5.00	70,000	
-6	Earth fill					
-61	Rolled fill					
-610	From borrow and spillway	1,112,000	cu yd	0.80	890,000	
-8	Slope protection					
-80	Gravel blanket	25,400	cu yd	4.00	102,000	
-81	Riprap (from spillway stockpile)	67,800	cu yd	1.00	68,000	
	Total slope protection				170,000	
	TOTAL EARTH DAM				1,977,000	
224	SLUICEWAYS					
-3	Conduit liners	7	ton	1,000.00	7,000	
-6	Water regulating equipment					
-60	Gates and appurtenances					
-600	Gate frames and guides	1	ton	1,000.00	1,000	
-601	Gates and seals	2	each	4,000.00	8,000	
-602	Operating equipment		L.S.		10,000	
-61	Main valves and operating equipment	2	each	28,000.00	56,000	
-62	Trash racks	1	ton	1,000.00	1,000	
-63	Bulkheads		L.S.		10,000	
	Total water regulating equipment				86,000	
-9	Electrical work		L.S.		6,000	
	TOTAL SLUICEWAYS				99,000	
	TOTAL RESERVOIRS, DAMS, AND WATERWAYS					$ 7,702,000
26	ROADS, RAILROADS, AND BRIDGES					
260	ACCESS ROADS FOR PERMANENT USE		L.S.		60,000	
	TOTAL ROADS, RAILROADS, AND BRIDGES					60,000
27	VILLAGE AND RESERVOIR FACILITIES					
271	VECTOR CONTROL FACILITIES		L.S.		330,000	
272	PUBLIC USE FACILITIES		L.S.		1,400,000	
	TOTAL VILLAGE AND RESERVOIR FACILITIES					1,730,000
	TOTAL DIRECT COST - COLUMBIA UNIT					34,606,000
	TOTAL DIRECT COST - DUCK RIVER PROJECT					50,314,000
	GENERAL CONSTRUCTION COSTS					
	Office of Engineering Design and Construction		L.S.		55,000	
	Construction - Construction Services Branch		L.S.		280,000	
	- Field Office		L.S.		3,400,000	
	Design		L.S.		1,875,000	
	Forestry		L.S.		8,000	
	Health and Safety - Regular		L.S.		176,000	
	- Compensation		L.S.		298,000	
	Materials		L.S.		163,000	
	Personnel		L.S.		155,000	
	Regional Studies		L.S.		110,000	
	Reservoir Properties		L.S.		380,000	
	Water Control Planning - Director's Office		L.S.		223,000	
	- Engineering Laboratory		L.S.		265,000	
	- Flood Control Branch		L.S.		57,000	
	- Geologic Branch		L.S.		152,000	
	- Hydraulic Data Branch		L.S.		65,000	
	- Maps and Surveys Branch		L.S.		799,000	
	- Project Planning Branch		L.S.		237,000	
	- River Control Branch		L.S.		29,000	
	Duck River Basin project indirect cost		L.S.		42,000	
	Administrative and General		L.S.		1,200,000	
	General Construction and Operation		L.S.		1,550,000	
	TOTAL GENERAL CONSTRUCTION COSTS					11,519,000
	CONTINGENCY ALLOWANCE					11,667,000
	TOTAL PROJECT COST					$73,500,000

Tennessee Valley Authority
Division of Water Control Planning
Geologic Branch

APPENDIX C

GEOLOGIC INVESTIGATIONS

Knoxville, Tennessee
September 1968

APPENDIX C

GEOLOGIC INVESTIGATIONS

In March 1966 seismic and surface investigations were made at several locations along the main stem of the Duck River in connection with planning studies of the Columbia, Normandy, and County Line Dam sites. Further study of the County Line site was discontinued because of the apparent difficulty that would be encountered in controlling leakage. In June 1966 an extensive geologic investigation was initiated at the Columbia site when wire line drills were moved in for core drilling purposes. Drilling at this site ended in February 1967 after 161 holes, totaling almost 18,000 linear feet, had been logged. The drills were moved to the Normandy Dam site in April 1967 and a core drilling program was carried out intermittently until March 1968. When terminated, almost 15,000 linear feet had been drilled and 110 holes logged.

The results of the geologic investigations at the Columbia and Normandy sites are discussed in detail in the following sections. Exhibits 12 through 14 cover the Normandy Dam site, and exhibits 16 through 21 the Columbia Dam site.

COLUMBIA DAM SITE

Scope of Investigation

Geologic investigation of the Columbia Dam site began in March 1966 with seismic and surface investigations along an axis at mile 136.7. In June 1966 wire line drills were moved in, and drilling began on the right bank of the river chiefly along two lines--a prolongation of the axis (range C) and a line 1200 feet upstream parallel to the axis (range P). The initial drilling indicated that treatment would be required at least as deep as the contact between the Carters and Lebanon Formations. Along range C this contact averaged 97 feet below the surface; whereas along range P it averaged 38 feet deep. As a result,

the axis of the dam was moved upstream to mile 136.9 and slightly realigned. (Exhibit 16 shows the location of core drilling.) Drilling along the left abutment was essentially normal to the new axis. In the flood plain additional drilling 200 feet upstream and 200 feet downstream was done to delineate a fault zone. One hole was inspected using television equipment borrowed from the Corps of Engineers. In selected holes, electric resistivity and gamma ray logs were run to aid correlation of key horizons and clay seams.

When drilling ended in February 1967, 161 holes, totaling 17,709.4 linear feet, had been drilled and logged. Geologic sections are shown on exhibits 17 through 21.

Physiography

The Columbia Dam site is located in the physiographic region called the Nashville Basin. This is a gently rolling oval lowland some 60 miles wide east and west by 120 miles long north and south, completely surrounded by a plateau called the Highland Rim. The general level of the Nashville Basin ranges from elevation 500 to elevation 750; whereas the Highland Rim is some 400 to 500 feet higher.

At some time in the geologic past, the rocks of the area were uplifted along an axis that trended northeast-southwest, roughly parallel to the Appalachian Mountains. Erosion of the rolling plain, of which the present Highland Rim is a remnant, was accelerated; the cherty limestones immediately underlying its surface were breached; and the more soluble limestones underlying them were, geologically speaking, rapidly eroded away by three master streams--the Elk River, the Duck River, and the Cumberland River. In this way the topographic basin was initially developed and gradually enlarged to its present size. However, the uplift of the region to its present altitude was not continuous. Instead, it occurred in several periods, interrupted by intervals of repose. During these intervals, the downward cutting of the streams was interrupted, and their valleys were widened. When the region was again uplifted, downcutting began again, resulting in the creation of a new narrower valley within the older wider one.

At the Columbia site, the axis is just upstream from the head of an island where the river is about 300 feet wide at elevation 550. Banks nearly

20 feet high flank the river on both sides. The flood plain extends some 400 feet on the right bank and 500 feet on the left to the base of the abutments. The right abutment rises steeply from elevation 575 to elevation 620, then flattens and rises gradually to elevation 650 along the right rim. This higher surface is probably a remnant of an old flood plain. The left abutment rises sharply from elevation 600 nearly to elevation 700 in the crest of a narrow ridge that divides the watershed of the main river from that of its tributary, Lytle Creek.

Structure

Running in a general northeasterly direction through this area is a broad swell in the underlying rock strata known as the Cincinnati Arch. In general, the rock strata are inclined away from the axis of the arch in dips that run from 10 to 15 feet per mile. The regional dip, however, in many places is obscured or modified by minor warping and cross folding. Small normal faults, the result of adjustment to the warping and folding, occur frequently; but no major fault systems are known in the area. Two major sets of high-angle joints nearly at right angles to each other are very prominent structural features because, with the bedding planes, they control the development of solution cavities in the limestones.

At the dam site, the most prominent structural feature is the fault zone on the eastern side of the river. This zone was first recognized on the baseline between stations 40+00 and 41+33. Subsequent additional drilling allowed definition of the fault zone within the following limits:

Drill Line Location	Station Limits of Fault Zone	Displacement
200 feet upstream	39+75 to 39+95	10 feet
Baseline	40+64 to 41+30	10 feet
200 feet downstream	41+75 to 41+95	14 feet

On the geologic sections (exhibit 17), the feature is defined as a "multiple-fault zone." This term was chosen because of evidence of associated faulting, particularly on the baseline, which indicated additional movement in a general north-northwest to south-southeast direction. All three drill lines

evidenced appreciable solution associated with the fault zone. There appears, however, to be a concentration of solution features extending to the east for some distance beyond the fault zone. Very limited solution was recognized west of the zone.

Stratigraphy

The unconsolidated materials covering bedrock can be divided into two categories: (1) alluvial clays, silts, sands, and gravels deposited by the Duck River and (2) residuum derived from the decomposition of the bedrock. The alluvial materials blanket the flood plain and form the ancient terrace at the base of the right abutment. The greater part of the alluvium is silty to sandy clay, but some lenses of gravel were found near its base. Its thickness ranges from 10.5 to 33.5 feet, averaging 30 feet on the east side and 17 feet on the west. Throughout the residuum, which was found at higher elevations than the alluvium, there were pinnacles and detached boulders of incompletely weathered limestone. Along the west side there were many rock ledges exposed on the surface, but the east side was much better mantled with overburden than the west. The maximum depth of residuum found was 32 feet, and the average depth on the east rim was 17.5 feet.

Hermitage Formation--The Hermitage Formation is exposed chiefly at higher elevations near the dam site. It crops out along range P (exhibit 20) east of station 4+81, and on the higher portions of the left rim above the pool level. In this area the Hermitage Formation consists of about 70 feet of thin-bedded to laminated argillaceous limestone and shale. Individual beds of limestone ranging from 1 to 10 inches thick are separated by fissile dark gray to black shale ranging in thickness from mere partings to discrete beds a foot thick. Because of the numerous partings, cores from the Hermitage break down into "poker chips" after a few weeks exposure.

Carters Limestone--The Carters Limestone is exposed on both the right and the left abutments and rims of the dam site above approximate elevation 620, (exhibits 20 and 21). It is a dark-gray to dove-gray limestone, varying in texture from fine to coarse. Most of the beds range from 1 to 4 feet in thickness. Some of them are separated from the adjacent beds by thin seams of clay or shale.

Much of the fine-grained limestone is very dense, dove colored, extremely brittle, and has a conchoidal fracture. The average thickness of the formation at the site is about 67 feet.

As a foundation material at the Columbia site, the Carters Limestone will create problems. In areas where it is no longer protected by the Hermitage Formation, a deep, rectilinear, joint-controlled solution pattern is present. An example may be noted on the left rim, where primary solution has developed along near-vertical joints and secondary solution has followed the bedding planes. The results of such weathering are massive pinnacles and isolated monoliths. Extensive treatment will be required to prevent leakage beneath any portion of the dam founded directly on this formation. Sinkholes are common in the outcrop area of the Carters in the right rim.

Rock from the Carters Limestone would probably be satisfactory for riprap and concrete aggregate here, but it should be tested before use. In 1960, the Tennessee Department of Highways tested some samples from a quarry at Godwin, some 4 miles from the dam site, in the Carters Limestone, with the following results:

Specific gravity	2.66
Los Angeles abrasion loss	23.80 percent
Sodium sulphate loss	7.31 percent

The losses indicated by these tests are somewhat higher than normal. Since they are measures of the durability of the rock under severe wear and conditions of alternate freezing and thawing, it is suggested that any proposed source of aggregate from the Carters in this area be thoroughly tested before it is accepted.

Compressive strength normal to the bedding plane is expected to exceed 9000 pounds per square inch, but the tensile strength will vary depending on the location of the sample with respect to the shale partings. Shear strength in unweathered material should be moderate to high. The specific gravity ranges from 2.6 to 2.7, and the average weight is about 165 pounds per cubic foot.

Lebanon Limestone--This formation will be encountered in the abutments of the site below the approximate elevation 620 and all across the flood plain and the bed of the river. It is composed of beds of blue-to-gray, fine- to coarse-

grained, mottled and banded limestone averaging 2 or 3 inches thick, separated by gray calcareous shale ranging in thickness from partings to beds 2 inches thick. Near the surface the shale has been weathered to incipient clay seams. At various depth, thin persistent gypsum seams have developed in the shales. Total thickness of the Lebanon in the Columbia Dam site area is about 105 feet. About 45 feet below the top, a prominent zone of claystone or calcareous siltstone 0.8 foot thick is present, which was used as a key horizon for correlation of drill logs and is designated "LK."

Where the Lebanon Limestone is covered by at least 15 feet of the Carters Limestone, weathering is limited to partial decomposition of a few thin shales. In the flood plain, a more pronounced deterioration was observed. Most of the areas of total decomposition, represented by clay-filled cavities, were found in the fault zone under the right flood plain. In two zones, one located 40 to 54 feet and the other 60 to 91 feet below the top of the formation, the physical characteristics of the rock would permit rapid mechanical decomposition upon alternate wetting and drying.

As a foundation material, the Lebanon Limestone should be carefully evaluated, taking into account the type of structure planned and the depth of the foundation. Many bedding planes contain a thin film of material that becomes slippery when wet, and shear values on weak or partially weathered shales may be quite low. Some cores contained gypsum layers up to 0.1 inch thick. Where the formation is protected by the Carters Limestone and can be quarried, the top 30 feet may be suitable for use as road material, filter material, or fill; but none of it is suitable for exposed riprap.

Ridley Limestone--The lowest geologic unit that may be involved in construction of a dam at the Columbia site is the Ridley Limestone. It is not exposed anywhere near the site, but it lies only 28 feet below the top of rock in the river channel, and it would be involved in curtain grouting under the dam. Approximately 9.5 to 10.5 feet below the Lebanon-Ridley contact, there is a very persistent 0.1- to 0.2-foot-thick, weathered bedding plane. In some places a cavity, either open or filled, is associated with the bedding plane.

In appearance, the Ridley is very similar to the Carters Limestone; and if it were not for the intervening thin-bedded Lebanon Limestone, they would be difficult to distinguish. Most of the formation consists of gray to blue-gray, fine- to coarse-grained, slightly banded limestone. Some beds are dolomitic and have a "sugary" texture. The beds are massive--up to 4 feet thick--and many of them are separated by thin shale partings. A key layer 0.5 foot thick situated 6.5 to 7.5 feet below the Lebanon-Ridley contact was designated the R-2 horizon for purposes of correlation between drill holes because it was easily recognizable by the comparative absence of shaly bands.

Earthquake Potential

The Columbia area is considered to be seismically stable. Records published by Moneymaker[1] covering the earthquake history of Tennessee from 1699 to 1950 indicate that the nearest epicenter of a major quake is the New Madrid area over 170 miles to the northwest, while the closest epicenter of a minor quake is in the vicinity of Huntsville, Alabama, some 60 miles to the south. From all indications, infrequent shocks felt in the Columbia area have not exceeded an intensity of 5 on the Wood-Newman scale (felt by most people; some breakage of dishes, windows, and plaster; disturbance of tall objects). Acceleration equivalents for this range approximate 20 to 30 cm/sec^2 or 0.02 to 0.03 g.

Recommendation

The following recommendations are made concerning the site at mile 136.9.

Dam

1. Between stations 37+00 and 50+00 the Lebanon Limestone has many horizons which imply low shear values. It is suggested that the entire thickness of Lebanon between these stations should be considered as a questionable unit rather than attempting to evaluate the integrity and continuity of any given individual horizon.

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1. B. C. Moneymaker, Journal of the Tennessee Academy of Science, vol. 29, No. 3 (1954); vol. 30, No. 3 (1955); vol. 32, No. 2 (1957); vol 33, No. 3 (1958).

2. Irrespective of the type structure which may be built, a grout curtain is recommended if the hydrostatic head is to exceed 25 feet. From station 37+00 to station 50+00, the curtain should extend a minimum of 40 feet into the Ridley Limestone.

3. Any portion of the Lebanon Limestone which may be exposed in the foundation preparation for a concrete dam should be covered with concrete or "gunite" as soon as possible.

4. The Carters Limestone in the left abutment, if beneath pool level, should be treated with a grouted cutoff curtain to a distance of at least 100 feet beyond the end of the structure.

Spillway

1. Where the Lebanon Limestone is to be exposed to high-volume, high-velocity flow or a hydraulic jump, severe erosion may be anticipated. If a side-hill spillway is considered, paving may be required in the Lebanon Limestone. For geologic section along station 35+00, see exhibit 18.

Right Rim

1. If pool level is to exceed elevation 610, and especially if an earth dike is to be constructed on the right rim, it is recommended that the Carters Limestone should be thoroughly treated with angle grout holes. The grout curtain should extend at least 10 feet into the Lebanon Limestone.

2. Two springs, situated on the north flank and at the base of the right rim, should be continuously gaged during and after construction to evaluate possible leakage.

Left Rim

1. Much of the left rim is capped by the Hermitage Formation. When this is the case, solution in the underlying Carters Limestone is considerably reduced. For a pool level at elevations 630 or 640 a grout curtain probably would not be required on the left rim except where the distance through the rim at pool level is less than 1000 feet.

Conclusion

There is no apparent reason why the Columbia site at mile 136.9 could not sustain a properly designed hydro structure. Physical quality of the rock should remain very similar within several thousand feet upstream or downstream from mile 136.9. The fault zone will probably extend into the east abutment or rim area at 2000 feet upstream, but it appears to follow the river downstream for a considerably greater distance.

NORMANDY DAM SITE

Scope of Investigation

Geologic investigations of the Normandy site began in March 1966 with seismic and surface investigations. Core drilling with wire line drills started in April 1967 and continued intermittently until March 1968. Drilling was concentrated along the proposed axis of the dam (range L) with additional holes 200 feet upstream and downstream from the axis and at two proposed spillway sites (see exhibit 12). In selected holes electric resistivity and gamma ray logs were run to aid correlation of key horizons and clay seams.

When drilling was terminated in March 1968, 110 holes, totaling 14,760 linear feet, had been drilled and logged. Geologic sections are shown on exhibits 13 and 14.

Physiography

The Normandy site lies on the border between the Nashville Basin and the Eastern Highland Rim sections of the Interior Low Plateau physiographic province. The valley area at the site is typical of the Nashville Basin area to the west, while the surrounding high ground is representative of the Highland Rim section to the east.

The present topography is the result of the dissection of a nearly level to gently undulating plain by the Duck River and its tributaries. In the vicinity of the Normandy site the surface of the Highland Rim is around

1100 feet above sea level and the valley floor of the Duck River is about 300 feet lower. The course of the river is sinuous, reflecting its prior meandering course on the Highland Rim peneplain. The tributary streams, however, lie in relatively straight, steep-sided valleys in which development has been controlled by the orientation of the joints in the underlying bedrock.

The uplift of the region to its present altitude has not been continuous but has occurred at several periods separated by intervals of repose. The downward cutting of the master stream, the Duck River, was correspondingly interrupted. Thus the river cut a rather broad valley to about 270 feet below the surface of the old plain; and, when the region was again uplifted, it cut a much narrower valley within this broad one. The remnants of the higher, broader valley are represented by terraces around elevation 830 in the site area.

Structure

The regional dip of the bedrock in the area of the dam site is to the east or southeast away from the axis of the Cincinnati Arch. In general, the rock strata are inclined away from the axis of the arch in dips of 10 to 15 feet per mile. This regional dip at the Normandy site is often obscured or modified by minor warping and cross folding. Here the strata on the right (west) abutment dip eastward at 3 degrees toward the river. This dip continues to approximately station 27+00 where it flattens in the trough of a minor syncline. Farther east, beyond station 31+00, the dip reverses and is 5 degrees to the west. This westward dip is still present at the eastern limit of the drilling at station 42+00 (exhibit 14).

No indications of faulting were observed in any of the cores drilled at the site. Jointing is the most prominent structural feature observable both in cores and in rock outcrops. Measurement of joints in cores from angle holes shows that there are two major sets nearly at right angles to each other. The major set varies from N 30° W to N 60° W with a maximum concentration at N 40° W. The minor set varies from N 20° E to N 40° E with a maximum at N 30° E. These high-angle joints have controlled the development of most of the solution cavities in the limestone (exhibits 13 and 14).

Stratigraphy

The unconsolidated materials covering bedrock can be divided into two categories: (1) alluvial clays, silts, sands, and gravels deposited by the Duck River and (2) residuum derived from the decomposition of the bedrock. Alluvial materials blanket the flood plain and make up the upper portion of the overburden on the terrace area between station 19+00 and station 27+00. The greater part of the alluvium is silty to sandy clay, but some lenses of sand and gravel are present near the base. Under the terrace blanket and on both abutments the overburden consists of residual clay and weathered rock fragments derived from the decomposition of the underlying limestone. Over the site the overburden was found to vary from a feather edge to a maximum of 75 feet. It averaged 14 feet on the right abutment; 10 feet in the flood plain; 10 feet in the terrace area (station 19+00 to station 27+00); and 12 feet on the left abutment.

Catheys Formation--The Catheys Formation is present on the steep right abutment above elevation 815; it underlies the terrace and residuum between stations 27+00 and 32+00 in the axis of the synclinal fold and is also present on the left abutment beyond station 41+00. It is a find- to medium-grained, medium- to dark-gray, thin-bedded limestone with interspersed bands of blue-gray shale. Near the bedrock surface many of the thin shale horizons have disintegrated into thin, but persistent, clay seams.

Cannon Limestone--The Cannon Limestone would be the foundation rock for the major portion of the dam and spillway. It is present on the right abutment below elevation 815 and underlies the base of the dam with the exception of the 500 feet between stations 27+00 and 32+00. The Cannon is made up of 117 feet of uniformly bedded, fine- to medium-grained, dark- to medium-gray limestone occurring in strata that range up to several feet in thickness but averaging about 1 foot. Approximately 20 feet above the base of the formation is a very distinctive bed of light-gray limestone slightly over a foot thick. It is designated on exhibits 13 and 14 as key horizon "LG." Another key horizon, "B," is 85 feet above the base of the Cannon Limestone. This unit is a foot of prominently banded limestone. These two horizons have been used for structural control between drill holes.

As a foundation material at the Normandy site, the Cannon Limestone would present some problems. In the first place, it contains less shaly material than any other formation in the area and, as a result, it apparently contains more solution cavities than the overlying Catheys or the underlying Hermitage Formations. The exploratory drilling indicates that cavities are developed primarily along near-vertical joints with secondary development along bedding. The majority of the cavities encountered in the drilling were found in the 45-degree angle holes which were more apt to intersect these vertical joints. In addition, clay seams along the bedding were found in the upper 20 to 40 feet of most cores. Two of these seams deserve special mention. Located 4 and 14 feet below the top of the Cannon Limestone are two seams of metabentonite, an altered volcanic ash. These seams apparently are less than 1/4 inch thick, but they will be continuous wherever these horizons occur in the site area.

Hermitage Formation--In all probability the Hermitage Formation would not be exposed in any excavations for a dam at the Normandy site, for the top of the formation is about 50 feet below the top of rock in the river channel. It would, however, be involved in curtain grouting under the dam. Drilling at the site indicates that the Hermitage Formation averages 55 feet thick. It consists of medium- to dark-gray, silty, nodular, argillaceous limestone and shale. The individual beds of limestone vary between 1 and 10 inches in thickness and are separated by fissile, dark-gray to black shale partings ranging from paper-thin laminae up to discrete beds a foot thick. Thin clay seams were detected in the cores recovered from the Hermitage. Many are the result of partial decomposition of thin shale partings, but five are thin continuous beds of metabentonite. These were found 14, 17, 28, 52, and 54.5 feet below the top of the formation. Considering the depth at which the Hermitage Formation is located below the rock surface, these seams should not affect the stability of the dam.

Carters Limestone--Approximately 87 feet of the Carters Limestone underlies the Hermitage Formation. The Carters consists of dark- to light-gray, fine- to coarse-grained, slightly cherty limestone. Bedding is commonly massive, much of it consisting of beds from 1 to 4 feet thick. Located 10 and 25 feet below the top of the Carters are the two thickest metabentonite beds known in this part of the geologic section. The upper bed varies from 2 to 2.5 feet in

thickness, while the lower bed ranges from 1/2 to 1 foot thick. At the Normandy site these metabentonites are too deeply buried to affect the structural stability of the dam.

Earthquake Potential

The Normandy area is considered to be seismically stable. Records published by Moneymaker[1] covering the earthquake history of Tennessee from 1699 to 1950 indicate that the nearest epicenter of a major quake is the New Madrid area over 170 miles to the northwest, while the closest epicenter of a minor quake is in the vicinity of Huntsville, Alabama, some 60 miles to the south. From all indications, infrequent shocks felt in the Normandy area have not exceeded an intensity of 5 on the Wood-Newman scale (felt by most people; some breakage of dishes, windows, and plaster; disturbance of tall objects). Acceleration equivalents for this range approximate 20 to 30 cm/sec^2 or 0.02 to 0.03 g.

Recommendation

The following recommendations are made for foundation treatment at the Normandy site.

Dam

1. The upper portion of the Cannon Limestone contains clay seams and two thin persistent metabentonite seams. Such seams imply low shear values, and it is necessary that these seams be adequately evaluated in relation to the stability of the dam.

2. For an earth fill, earth and dumped rockfill, or an earth and rolled rockfill dam, a cutoff trench exposing the foundation rock should be excavated. The exploratory drilling indicates the presence of numerous near-vertical solution channels at an oblique angle to the axis of the dam. These should be cleaned out and capped near the surface to prevent piping at the dam-rock interface.

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1. B. C. Moneymaker, Journal of the Tennessee Academy of Science, volume 29, No. 3 (1954); volume 30, No. 3 (1955); volume 32, No. 2 (1957); volume 33, No. 3 (1958).

3. An adequate grout curtain should be installed. Preferably this should be done from the bottom of the cutoff trench while this excavation is open. Between stations 14+00 and 22+00 and between stations 35+00 and 41+00, this curtain should be tied into the top of the Hermitage Formation--a depth varying from 50 feet to 100 feet. From stations 22+00 to 35+00, where the top of the Hermitage is deeper than 100 feet, the curtain should be at least 100 feet deep. To ensure maximum interception of all solution cavities developed along near-vertical joints, angle holes are recommended for the curtain drilling.

Spillway

1. For a side-hill spillway it is expected that paving will be required to prevent erosion under high-volume, high-velocity flows.

Reservoir Rims

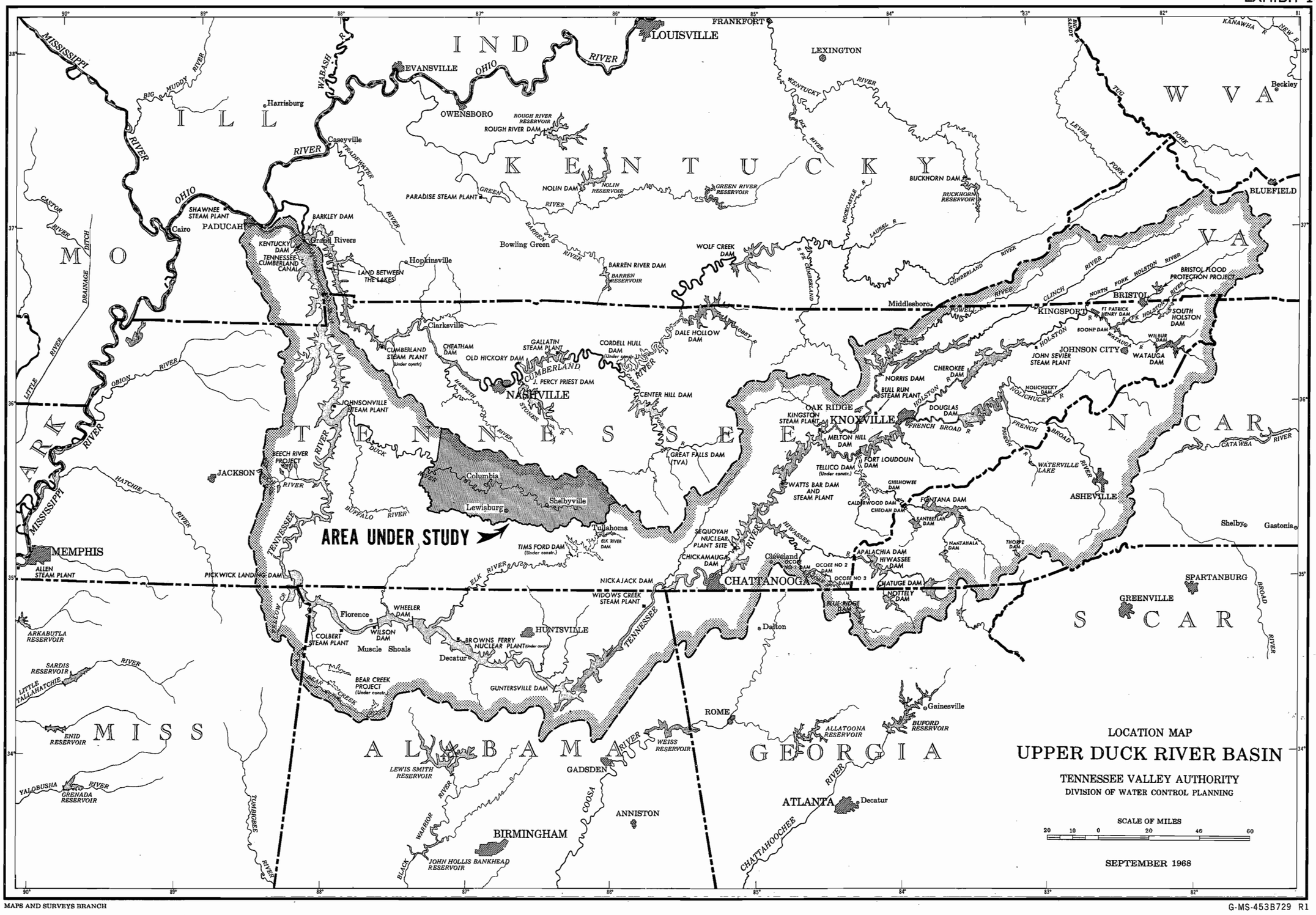
1. No major problems are anticipated with respect to leakage along either rim of the reservoir. There are two small gaps--one on each rim--that might be areas of potential leakage. On the right rim the gap, 1000 feet upstream from the right abutment, has a crest around elevation 950 which is 70 feet above proposed pool level. The lateral distance from the pool to elevation 880 on the downstream side is 1200 feet. Drilling in this area for a possible spillway showed sound rock above elevation 930. On the base of the width of the divide and the rock elevations, no leakage is anticipated and no treatment is recommended. The other area is the gap in the ridge 1000 feet southeast of the left abutment. The width of the divide is 1600 feet with a crest elevation around 965. Although no exploration has been done in this area, sound rock should be well above the proposed pool elevation and no grouting is recommended.

Conclusion

There is no geologic reason why the Normandy site at mile 248.6 would not be suitable for a properly designed dam. Near-vertical solution cavities will have to be treated in the upper 50 or more feet of rock and the sliding potential of clay seams near the rock surface will have to be taken into consideration. These conditions, however, would be encountered at any potential site in the vicinity.

EXHIBITS

EXHIBIT 1


AREA UNDER STUDY
LOCATION MAP
UPPER DUCK RIVER BASIN
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
SCALE OF MILES
20 10 0 20 40 60
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ILL
IND
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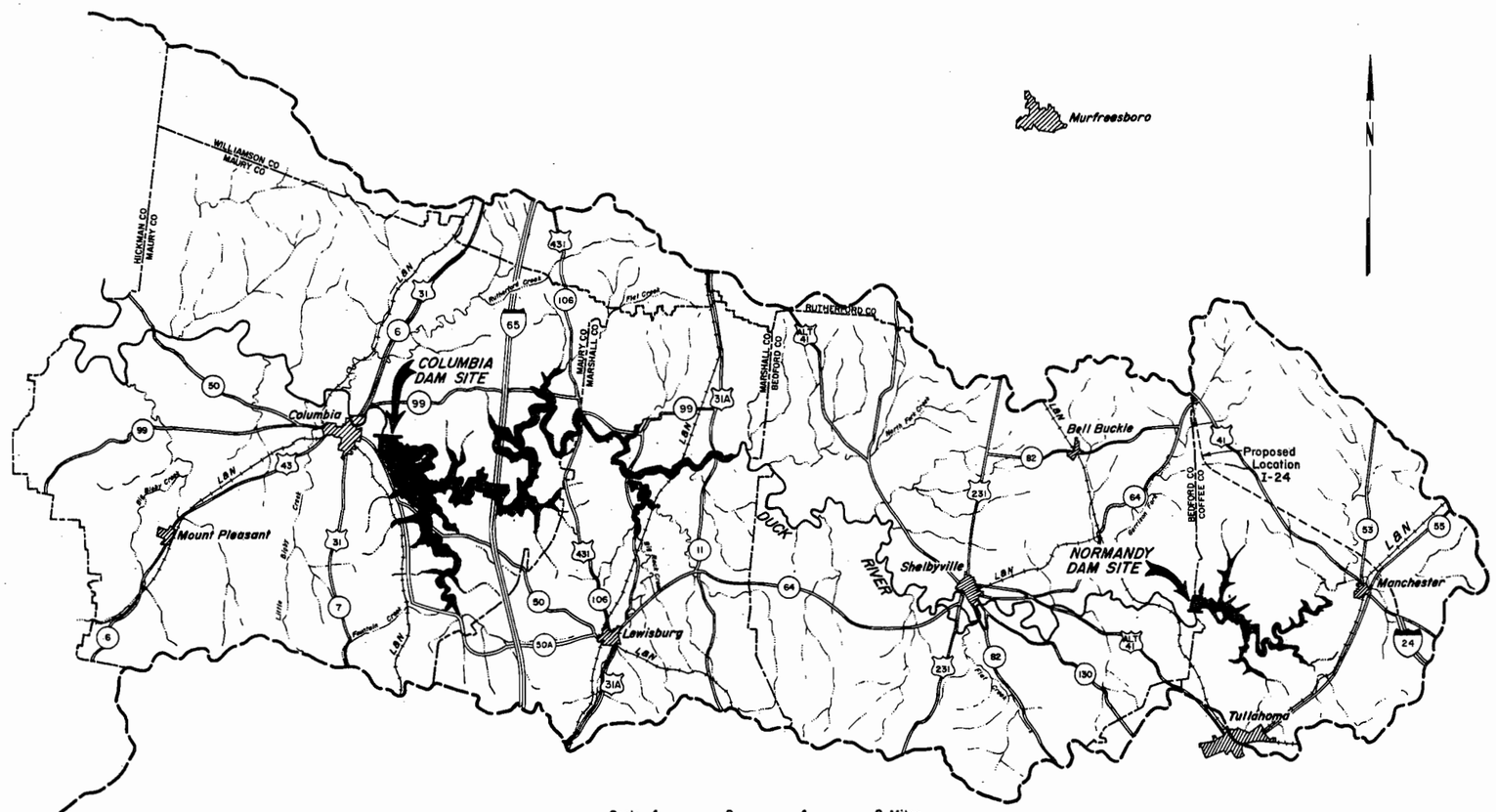
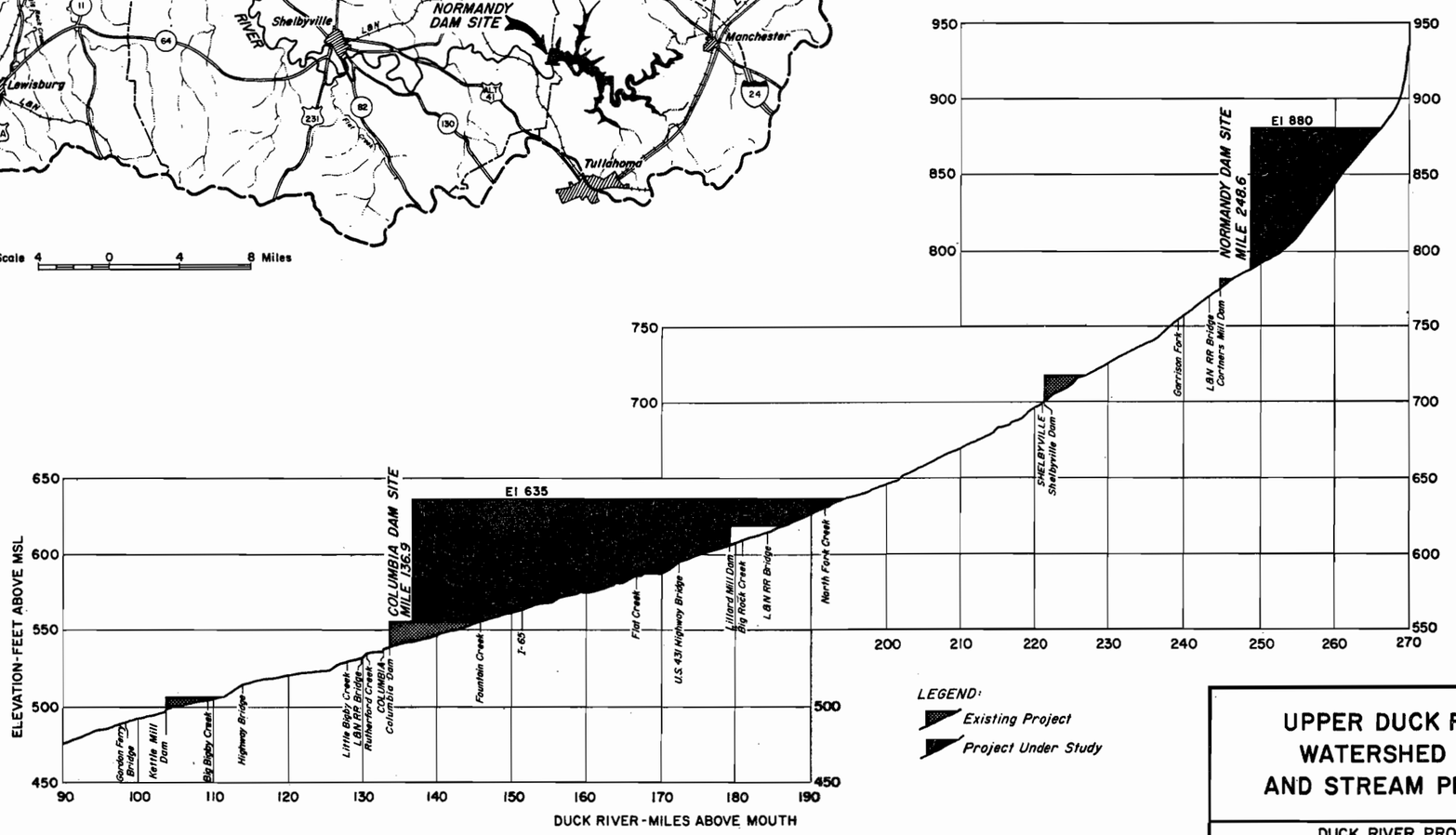
FRANKFORT
LEXINGTON
EVANSVILLE
OWENSBORO
Harrisburg
Caseyville
PADUCAH
Cairo
Grand Rivers
Hopkinsville
Bowling Green
Clarksville
NASHVILLE
Middlesboro
Beckley
BLUEFIELD
BRISTOL
KINGSPORT
JOHNSON CITY
KNOXVILLE
OAK RIDGE
ASHEVILLE
CHATTANOOGA
Dalton
ROME
ATLANTA
Decatur
Gainesville
GREENVILLE
SPARTANBURG
Shelby
Gastonia
JACKSON
Columbia
Lewisburg
Shelbyville
Tullahoma
MEMPHIS
Florence
Muscle Shoals
Decatur
HUNTSVILLE
GADSDEN
ANNISTON
BIRMINGHAM
Cleveland
Gainesville
OHIO RIVER
MISSISSIPPI RIVER
TENNESSEE RIVER
CUMBERLAND RIVER
KENTUCKY DAM
BARKLEY DAM
TENNESSEE-CUMBERLAND CANAL
LAND BETWEEN THE LAKES
BARREN RIVER DAM
BARREN RESERVOIR
WOLF CREEK DAM
DALE HOLLOW DAM
CORDELL HULL DAM
CENTER HILL DAM
OLD HICKORY DAM
CHEATHAM DAM
J. PERCY PRIEST DAM
GREAT FALLS DAM (TVA)
NORRIS DAM
CHEROKEE DAM
DOUGLAS DAM
FORT LOUDOUN DAM
MELTON HILL DAM
TELLICO DAM
WATTS BAR DAM AND STEAM PLANT
CHICKAMAUGA DAM
APALACHIA DAM
HIWASSEE DAM
OCOEE NO 1 DAM
OCOEE NO 2 DAM
OCOEE NO 3 DAM
BLUE RIDGE DAM
CHATUGE DAM
NOTTELY DAM
FONTANA DAM
CHILHOWEE DAM
CALDERWOOD DAM
CHEOAH DAM
SANTEETLAH DAM
NANTAHALA DAM
THORPE DAM
WATAUGA DAM
WILBUR DAM
BOONE DAM
SOUTH HOLSTON DAM
FT PATRICK HENRY DAM
BUCKHORN DAM
BUCKHORN RESERVOIR
NOLIN DAM
NOLIN RESERVOIR
GREEN RIVER RESERVOIR
ROUGH RIVER DAM
ROUGH RIVER RESERVOIR
PARADISE STEAM PLANT
SHAWNEE STEAM PLANT
CUMBERLAND STEAM PLANT (Under constr)
GALLATIN STEAM PLANT
JOHNSONVILLE STEAM PLANT
KINGSTON STEAM PLANT
BULL RUN STEAM PLANT
JOHN SEVIER STEAM PLANT
WIDOWS CREEK STEAM PLANT
COLBERT STEAM PLANT
ALLEN STEAM PLANT
SEQUOYAH NUCLEAR PLANT SITE
BROWNS FERRY NUCLEAR PLANT (Under constr)
BEAR CREEK PROJECT (Under constr)
TIMS FORD DAM (Under constr.)
TELLICO DAM (Under constr.)
BRISTOL FLOOD PROTECTION PROJECT
PICKWICK LANDING DAM
GUNTERSVILLE DAM
WHEELER DAM
WILSON DAM
BEECH RIVER PROJECT
ELK RIVER DAM
NICKAJACK DAM
ALLATOONA RESERVOIR
BUFORD RESERVOIR
WEISS RESERVOIR
LEWIS SMITH RESERVOIR
JOHN HOLLIS BANKHEAD RESERVOIR
SARDIS RESERVOIR
ENID RESERVOIR
GRENADA RESERVOIR
ARKABUTLA RESERVOIR
WATERVILLE LAKE
MAPS AND SURVEYS BRANCH
G-MS-453B729 R1

EXHIBIT 2





LEGEND:
- Existing Project
- Project Under Study

UPPER DUCK RIVER WATERSHED MAP AND STREAM PROFILE

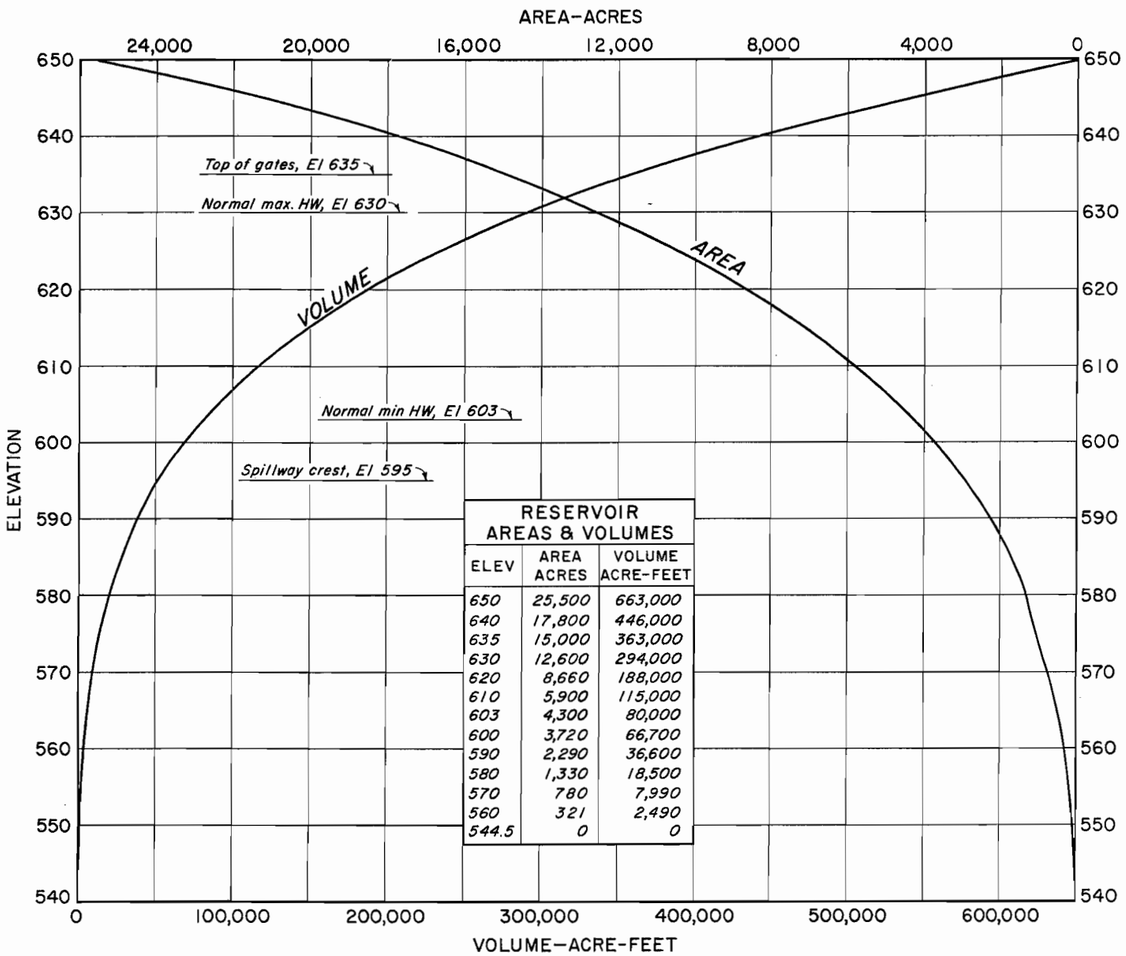
DUCK RIVER PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING

SUBMITTED	RECOMMENDED	APPROVED
Jos. Finger	Don H. Matthews	Glenn A. Ellis

KNOXVILLE	6-27-68	W	PP	1	301K69

REV NO.	DATE	MADE	CHKD	SUPV	INSP
DRWN EH DJC	COMPUTED				
TRCD	ENGINEER				
CHKD					

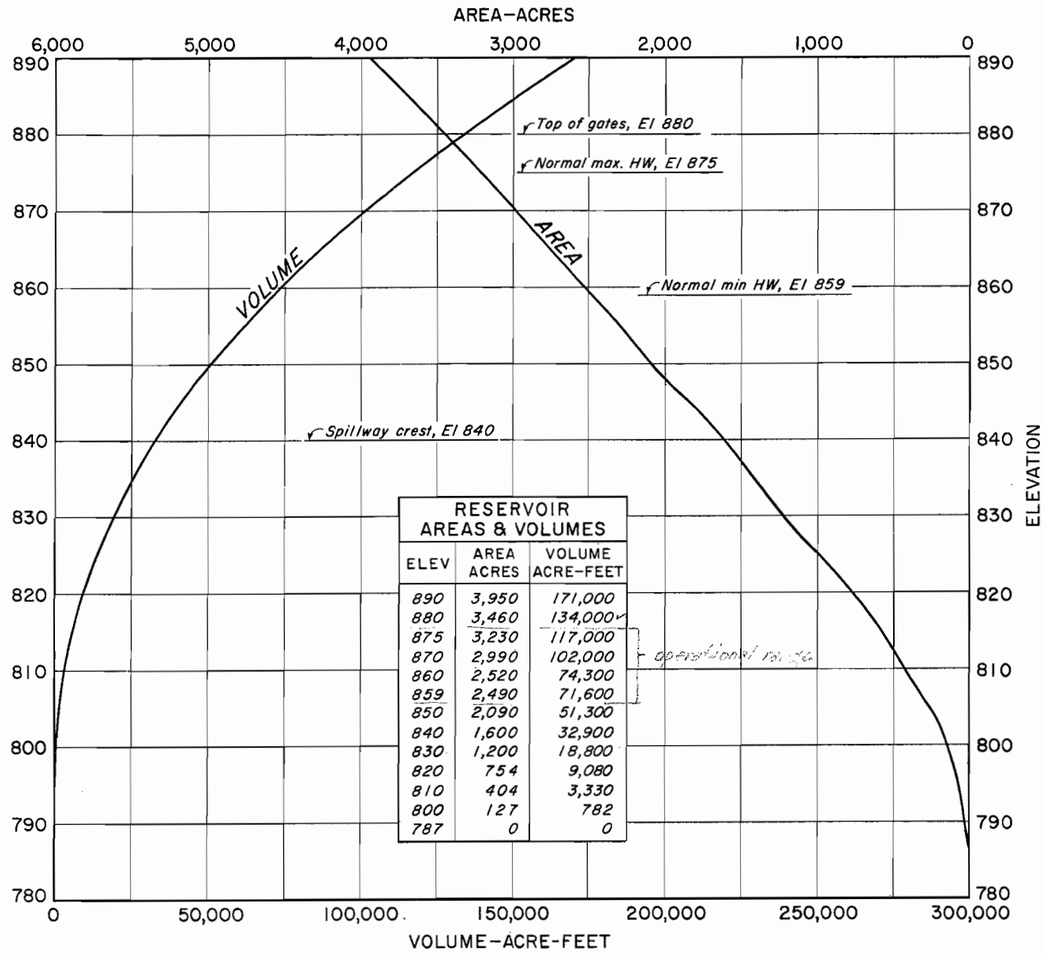
EXHIBIT 5



RESERVOIR AREAS & VOLUMES

ELEV	AREA ACRES	VOLUME ACRE-FEET
650	25,500	663,000
640	17,800	446,000
635	15,000	363,000
630	12,600	294,000
620	8,660	188,000
610	5,900	115,000
603	4,300	80,000
600	3,720	66,700
590	2,290	36,600
580	1,330	18,500
570	780	7,990
560	321	2,490
544.5	0	0

COLUMBIA UNIT
MILE 136.9



RESERVOIR AREAS & VOLUMES

ELEV	AREA ACRES	VOLUME ACRE-FEET
890	3,950	171,000
880	3,460	134,000
875	3,230	117,000
870	2,990	102,000
860	2,520	74,300
859	2,490	71,600
850	2,090	51,300
840	1,600	32,900
830	1,200	18,800
820	754	9,080
810	404	3,330
800	127	782
787	0	0

operational range

NORMANDY UNIT
MILE 248.6

NOTES:
1. Areas obtained by planimeter from USGS–TVA quadrangle maps; scale 1"=2000'; contour interval 10' and 20'.
2. Drainage area at Columbia site = 1,181 square miles; at Normandy site = 195 square miles.
3. Area of original river within reservoir to El 635 at Columbia site = 1,075 acres; to El 880 at Normandy site = 160 acres.

REV NO.	DATE	MADE	CHKD	SUPV	INSP
DRWN REH		COMPUTED			
TRCD		ENGINEER			
CHKD					

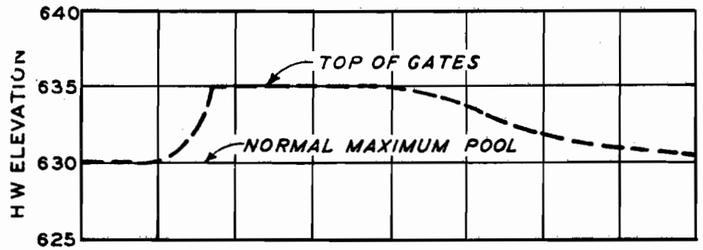
DUCK RIVER – MILES 136.9 AND 248.6

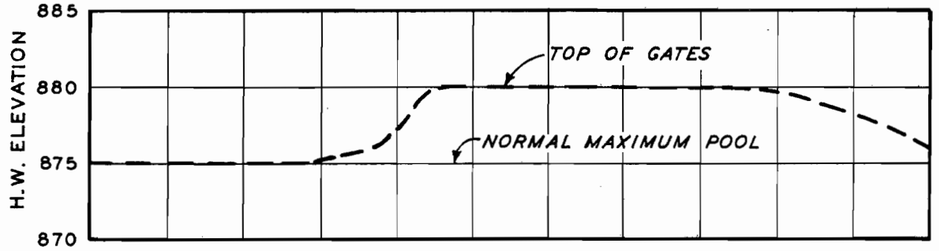
RESERVOIR AREAS AND VOLUMES

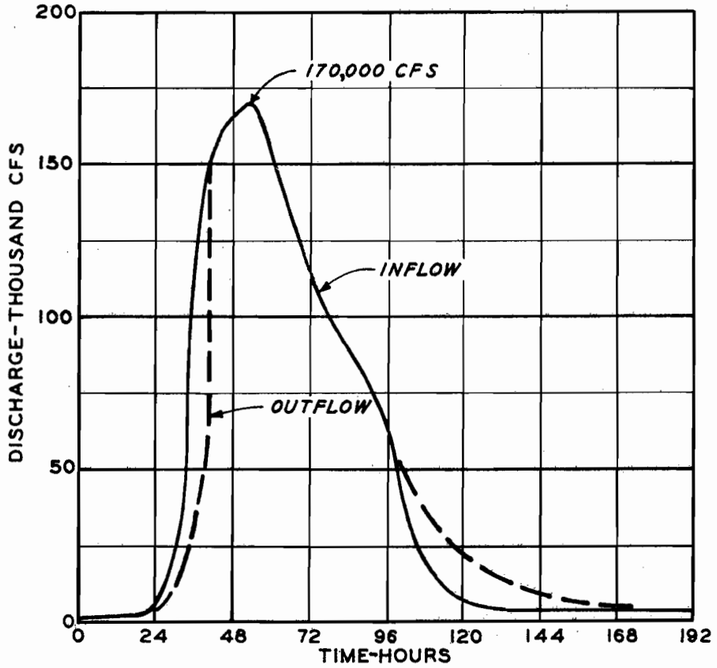
DUCK RIVER PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING

SUBMITTED	RECOMMENDED	APPROVED
J. L. Ferguson	Dan H. Matthews	R. A. Clark

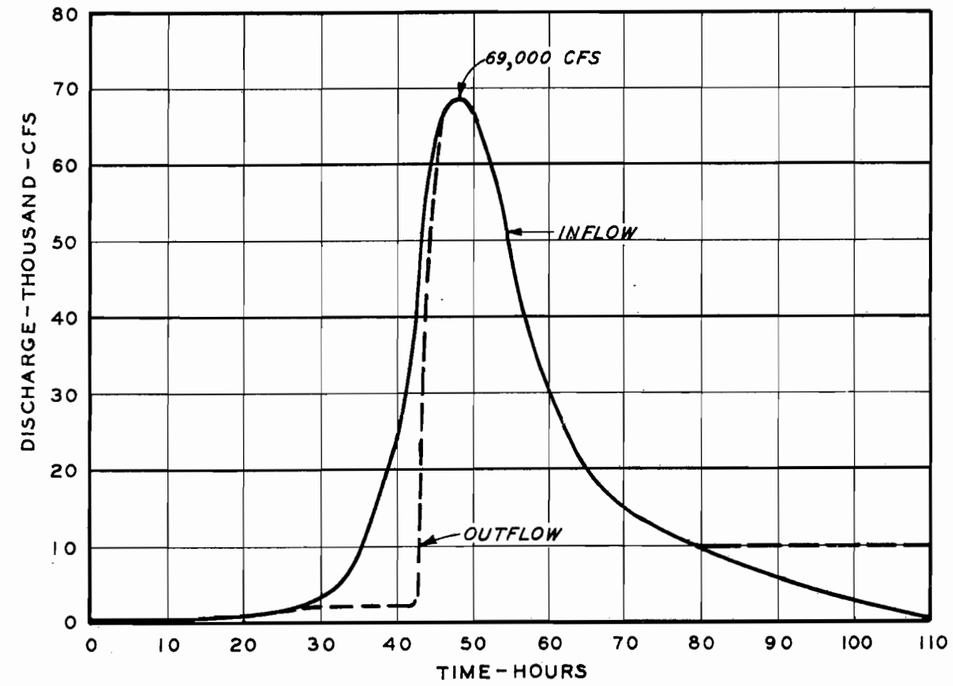
KNOXVILLE | 8-6-68 | W | PP | 1 | 321K858







COLUMBIA UNIT
MILE 136.9



NORMANDY UNIT
MILE 248.6

NOTE:
Operation is according to a guide appropriate for rare, large summer floods.

REV NO.	DATE	MADE	CHKD	SUPV	PROP
DRWN		COMPUTED			
TRCD MW		ENGINEER AGMC-EAM			
CHKD					

DUCK RIVER - MILES 136.9 AND 248.6

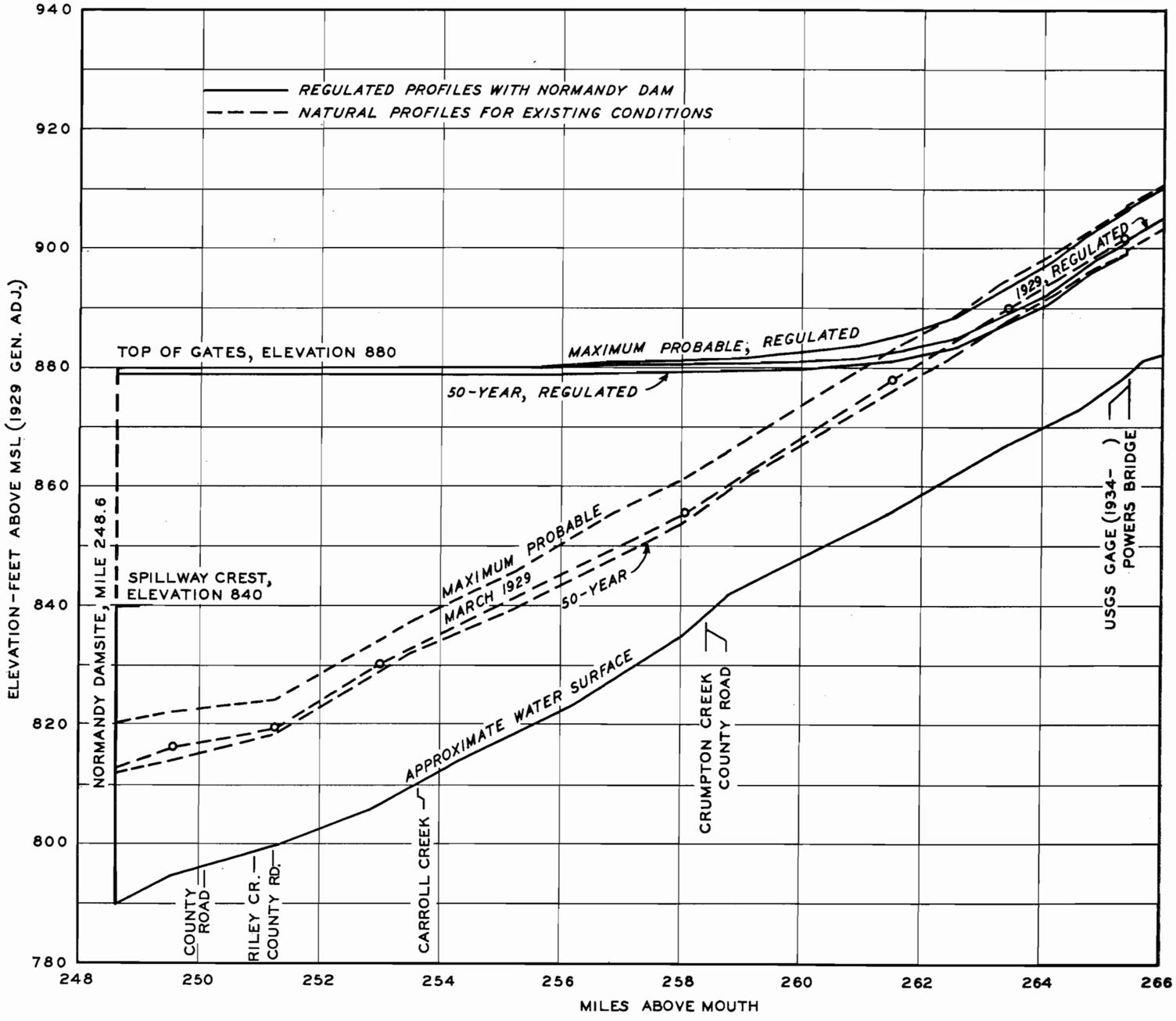
INFLOW AND OUTFLOW HYDROGRAPHS
MAXIMUM PROBABLE FLOOD

DUCK RIVER PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING

SUBMITTED	RECOMMENDED	APPROVED
Donald W. Kent	Rod J. Bubbles	R. E. Elliott

KNOXVILLE	8-2-68	W	FC	1	3218856

EXHIBIT 5



REV NO.	DATE	MADE	CHKD	SUPV	INSP
DRWN BCH, CDS		COMPUTED C.D.S.			
TRCD RHL		ENGINEER L.A. Gillett			
CHKD					

NORMANDY UNIT
DUCK RIVER, MILES 248.6 - 266.0

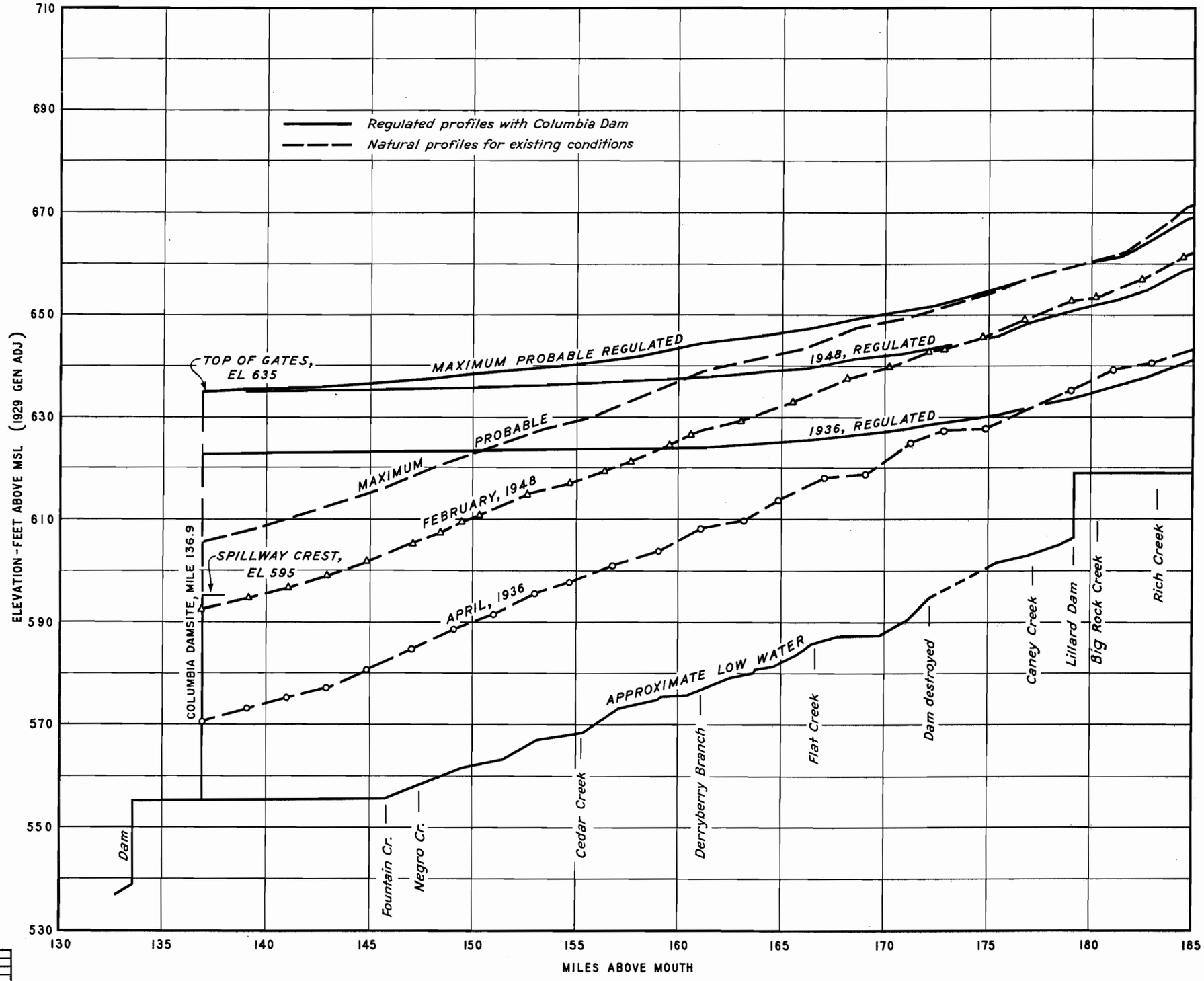
NATURAL AND REGULATED FLOOD PROFILES

DUCK RIVER PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING

SUBMITTED	RECOMMENDED	APPROVED
D.W. Newton	A.J. Buehler	R.G. Elliott

KNOXVILLE	6-6-68	W	FC	1	311B380Ro

EXHIBIT 6



REV NO.	DATE	MADE	CHKD	SUPV	INSP
DRWN		COMPUTED H.K.P.			
TRCD		ENGINEER C. D. S. - H. K. P.			
CHKD					

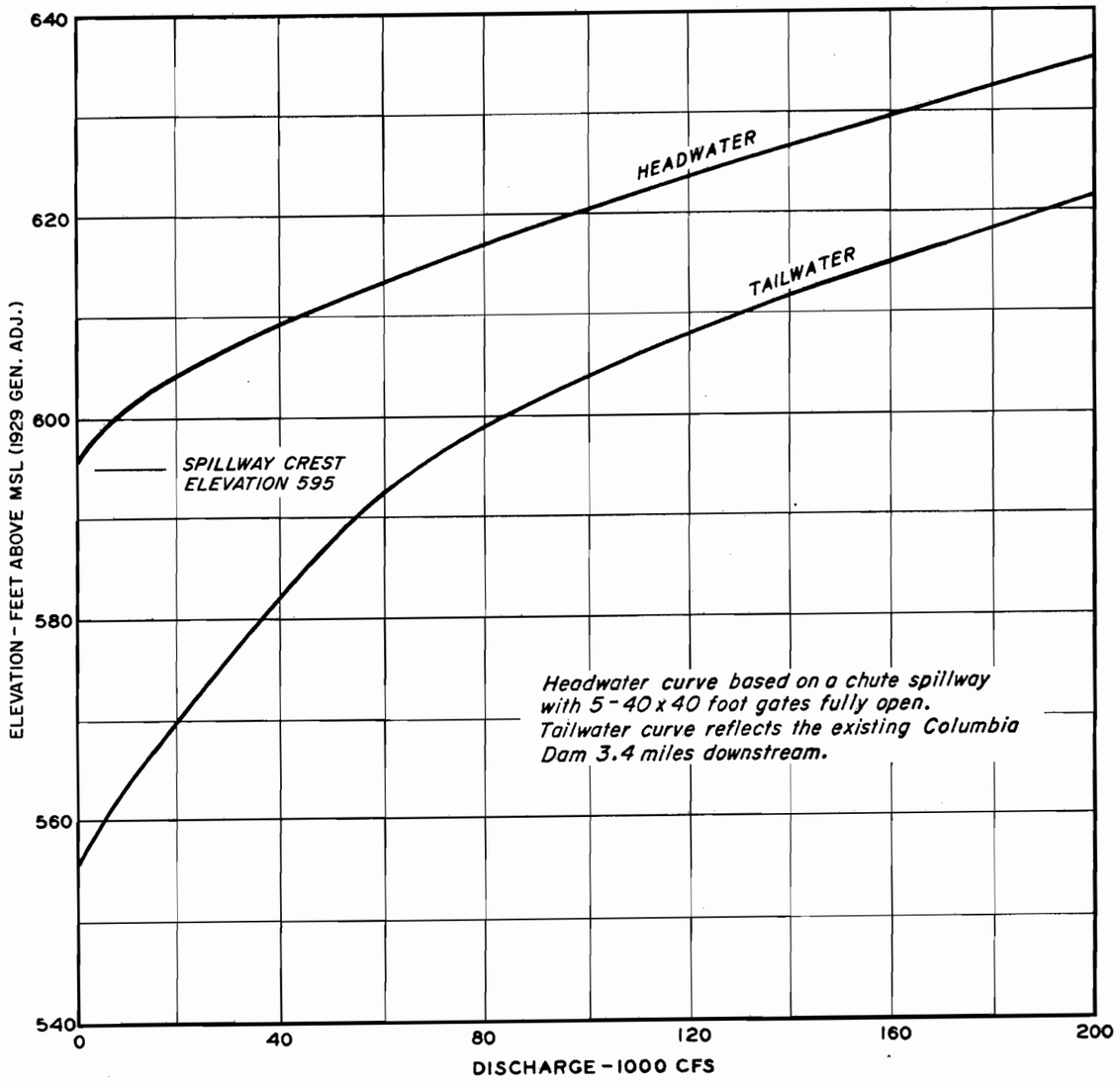
COLUMBIA UNIT
DUCK RIVER, MILES 135 - 185

NATURAL AND REGULATED FLOOD PROFILES

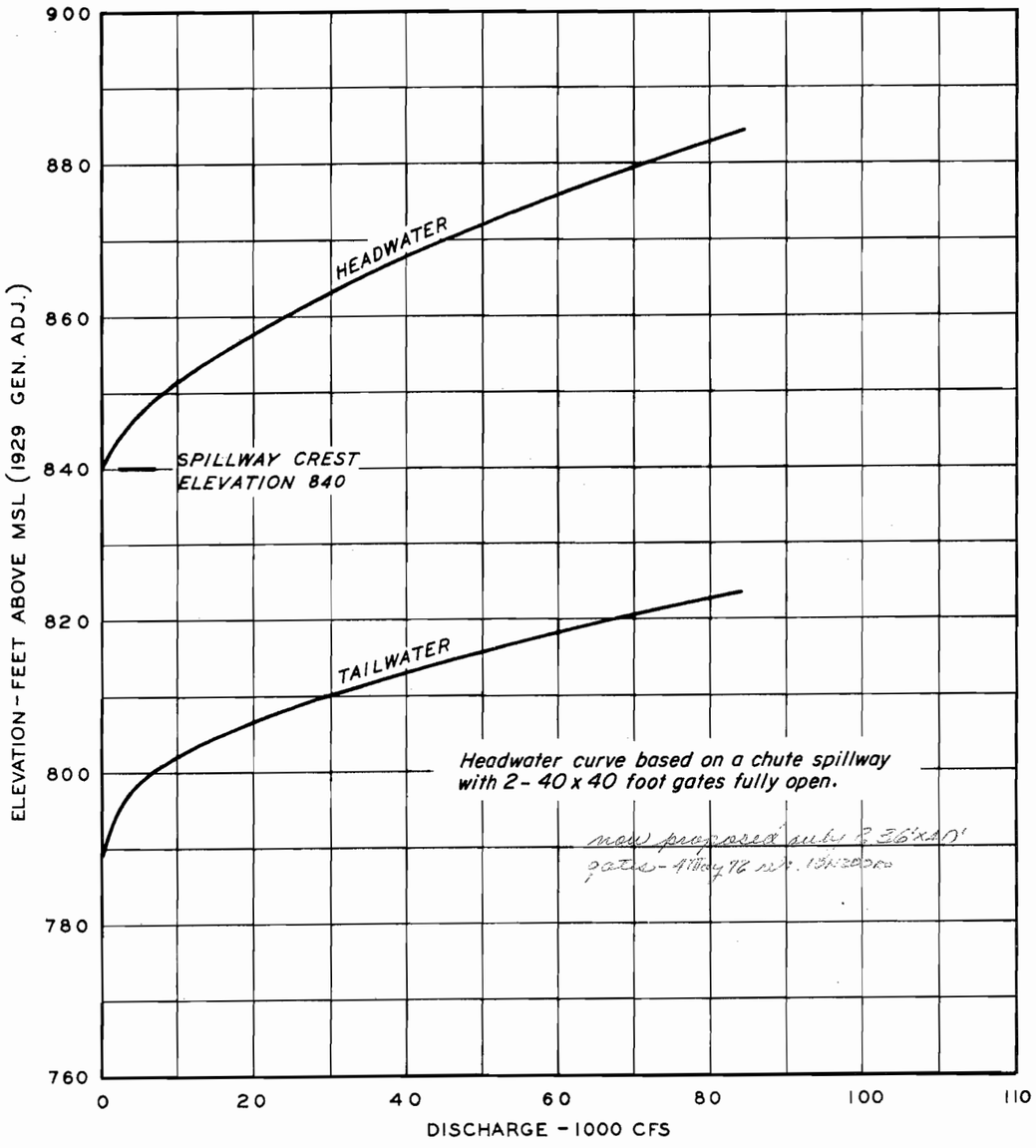
DUCK RIVER PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING

SUBMITTED	RECOMMENDED	APPROVED
L. A. Gillett	Rod Bushler	R. C. Ellard

KNOXVILLE	5-26-67	W	FC	1	3118376



COLUMBIA UNIT
MILE 136.9



NORMANDY UNIT
MILE 248.6

REV NO.	DATE	MADE	CHKD	SUPV	INSP
DRWN MW		COMPUTED C.D.S.			
TRCD		ENGINEER L.A.G.			
CHKD					

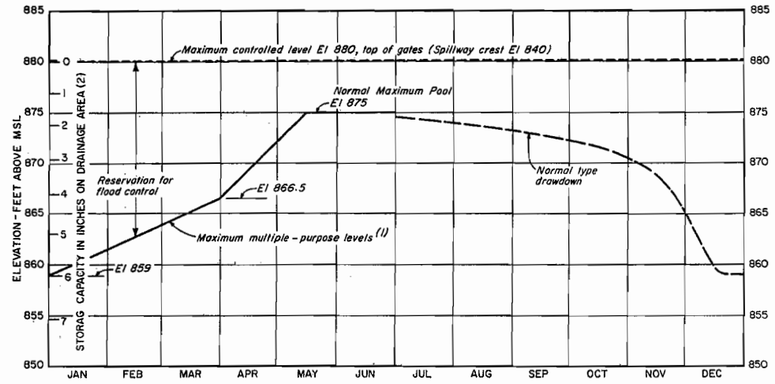
DUCK RIVER - MILES 136.9 AND 248.6

HEADWATER & TAILWATER RATING CURVES

DUCK RIVER PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING

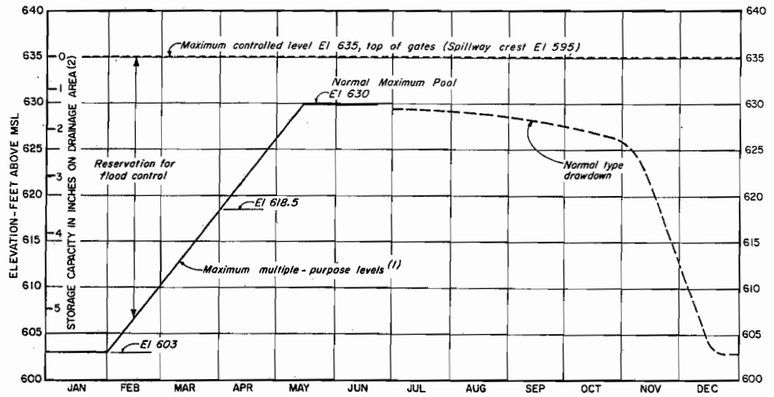
SUBMITTED	RECOMMENDED	APPROVED
D.W. Newton	A.J. Bubbles	R.G. Elliott

KNOXVILLE	8-6-68	W	FC	1	321B857


ELEVATION - FEET ABOVE MSL
STORAG CAPACITY IN INCHES ON DRAINAGE AREA (2)
Maximum controlled level El 880, top of gates (Spillway crest El 840)
Normal Maximum Pool El 875
Reservation for flood control
El 866.5
Maximum multiple-purpose levels (1)
El 859
Normal type drawdown
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

NOTES:
(1) To be exceeded only during flood operations.
(2) Based on drainage area, 195 square miles.

NORMANDY UNIT


ELEVATION - FEET ABOVE MSL
STORAGE CAPACITY IN INCHES ON DRAINAGE AREA (2)
Maximum controlled level El 635, top of gates (Spillway crest El 595)
Normal Maximum Pool El 630
Reservation for flood control
El 618.5
Maximum multiple-purpose levels (1)
El 603
Normal type drawdown
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

NOTES:
(1) To be exceeded only during flood operations.
(2) Based on drainage area at Columbia Unit less drainage area at Normandy Unit (1,181 - 195 = 986 square miles)

COLUMBIA UNIT

REV NO.	DATE	MADE	CHKD	SUPV	INSP

DRWN MTW | COMPUTED WRP
TRCD | ENGINEER J.C. Patterson
CHKD WRP

NORMANDY AND COLUMBIA UNITS

TENTATIVE MULTIPLE-PURPOSE RESERVOIR OPERATION

DUCK RIVER PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING

SUBMITTED	RECOMMENDED	APPROVED
Julian P. Hinton	Don H. Matthews	R. G. Ellenwood

KNOXVILLE	8-14-68	W	PP	1	321G2034

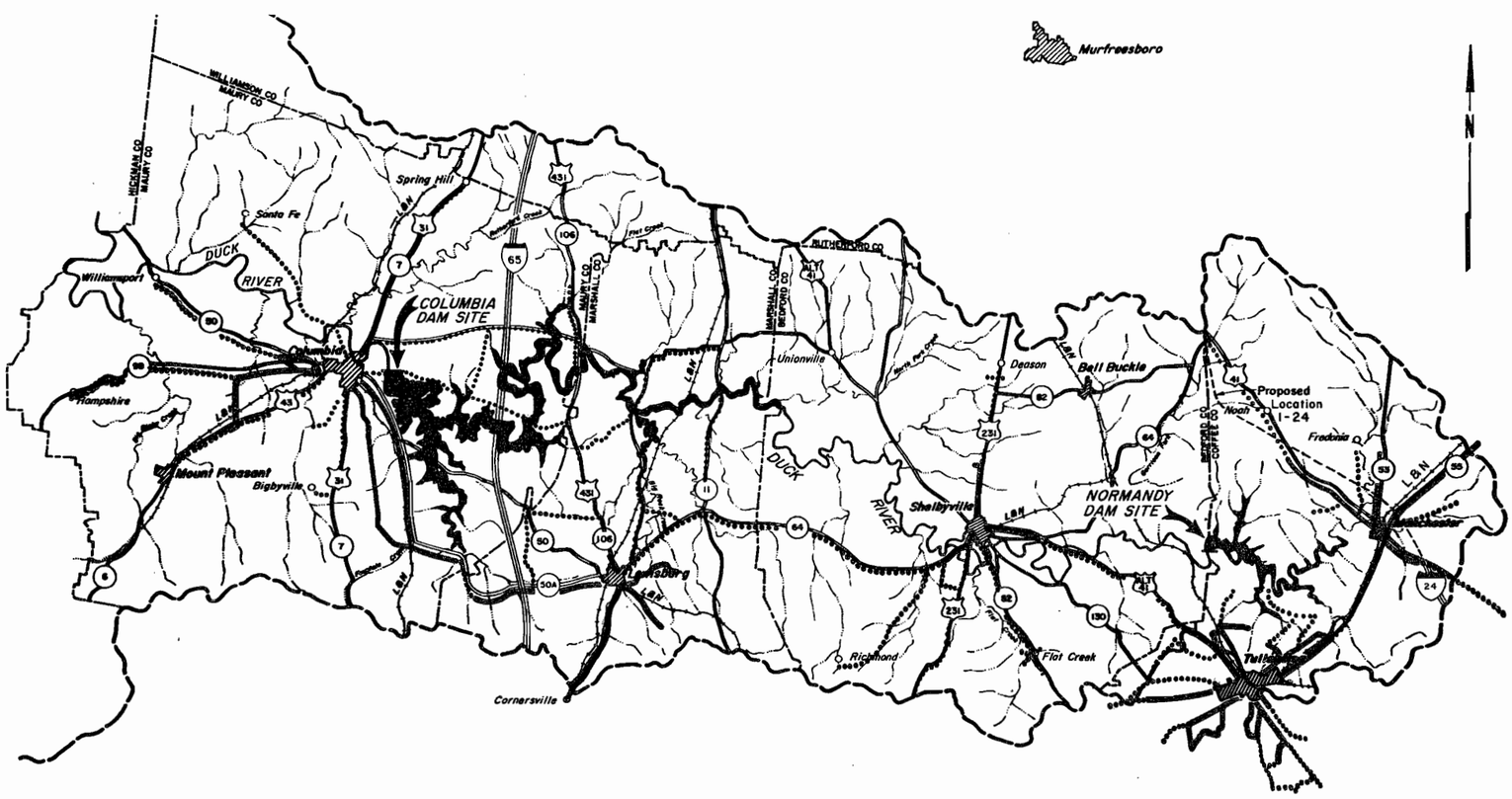

Murfreesboro
N
WILLIAMSON CO
MAURY CO
HICKMAN CO
MAURY CO
Spring Hill
Santa Fe
DUCK
RIVER
Williamsport
COLUMBIA
DAM SITE
MAURY CO
MARSHALL CO
BUTLER CO
MAURY CO
HICKMAN CO
HICKMAN CO
RICHLAND CREEK
Fort Creek
Unionville
Dean Fork
Dayson
Bell Buckle
Proposed
Location
I-24
Hoods
Fredonia
Hampshire
Mount Pleasant
Big Bynum Creek
Big Bynum Creek
Big Bynum Creek

EXHIBIT 10

NORMANDY DAM SITE

MANCHESTER

Old Stone Fort State Park

ARNOLD ENGINEERING DEVELOPMENT CENTER (U S AIR FORCE)

TULLAHOMA

NOTE:

1. Reservoir shown at normal maximum level El 875.

SCALE ½ 0 ½ 1 MILE

REV NO.	DATE	MADE	CHKD	SUPV	INSP

DRWN MTW COMPUTED

TRCD ENGINEER

CHKD

NORMANDY UNIT
DUCK RIVER-MILE 248.6

RESERVOIR MAP

DUCK RIVER PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING

SUBMITTED	RECOMMENDED	APPROVED
J. L. Ferguson	Donald H. Matthews	R. G. Elliott

KNOXVILLE	8-9-68	W	PP	1	462K10

EXHIBIT 11

CEDAR CREEK
WATERFOWL REFUGE

MAURY CO
MARSHALL CO

MARSHALL CO
BEDFORD CO

NOTES:

1. Reservoir shown at normal maximum level, El 630.

SCALE ½ 0 ½ 1 MILE

COLUMBIA UNIT
DUCK RIVER - MILE 136.9

RESERVOIR MAP

DUCK RIVER PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING

SUBMITTED	RECOMMENDED	APPROVED
J. L. Ferguson	Dan H. Matthews	R. L. Clark

KNOXVILLE	8-13-68	W	PP	1	453D329

COLUMBIA

COLUMBIA DAM SITE

CEDAR CREEK WATERFOWL REFUGE

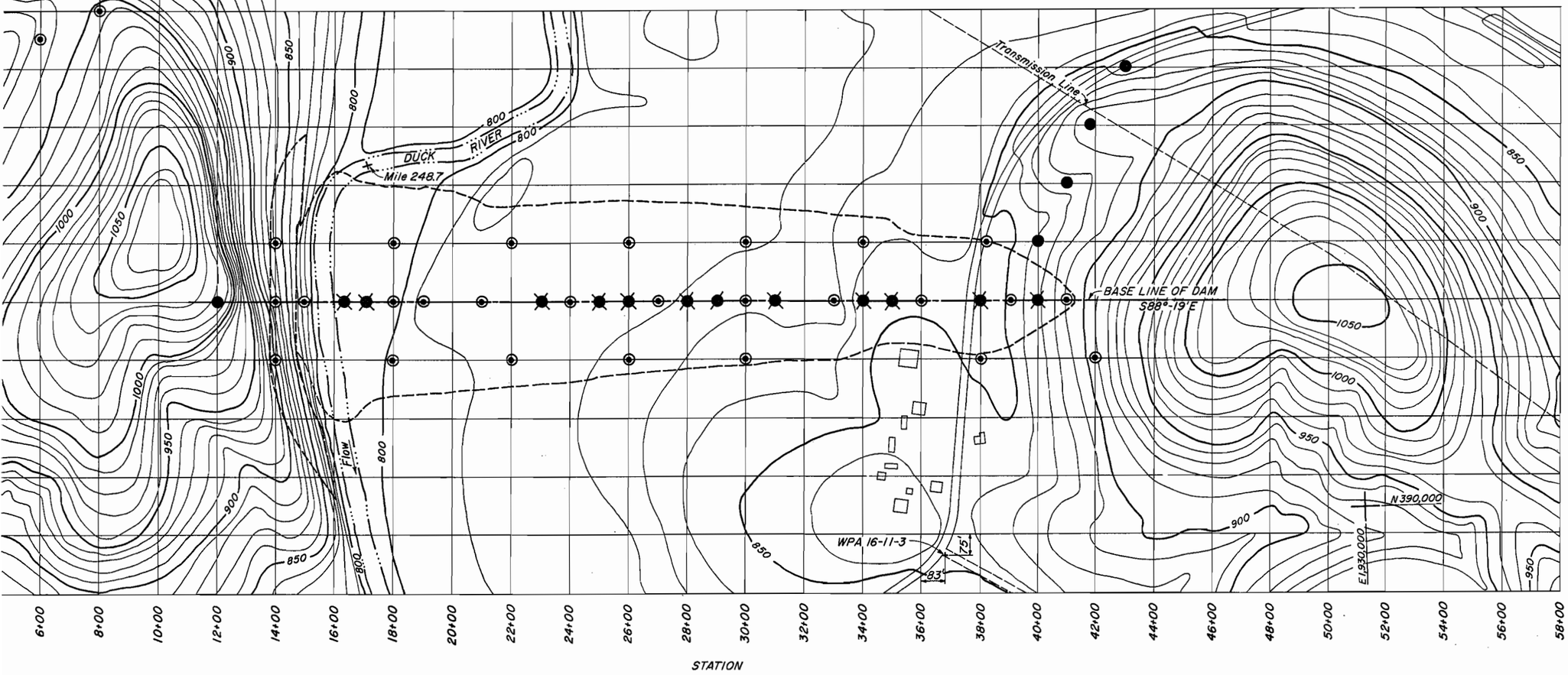
MAURY CO
MARSHALL CO

Oakland
Jones Cem
Undergound
Strip mines
Hardison Cem
Dabbletown
Flat Creek
Sharp Corner Church
Pottsville
Rally Hill School
Silo
New Bethel Ch
Lively
New Macedonia Ch
Macedonia Cem
Ring Cem
Cem
Iron Bridge
Radio tower
Negro Island
Sowell Mill Bridge
Union Grove
Cannon Bend
Davis Blurt
Vaughan Bend
Blue Spring
Rock Springs Church
Strip mine
Butter Pat Island
Rattle Fist Island
Carpenter's Bridge
Tucks Bend
Gundy Ford Island
Hooper Island
Sowell Bend
Sowell Ford
Hardison Mill
Osteen Bend
Cathey Cem
Silo
Caney
Howard Bridge
Whitworth Bend
Branch Islands
Rieves Bend
Bull Bluff
Jollys Ford Island
Cole Bend
Venable Spring
McLean Bend
Allen Cem
Caney Spring
New Hebrew Ch
Whitehead Spring
Bethlehem Ch
Bethlehem Cem
Antioch Ch
Leftwich
Milltown
Lillard Mill
Fountain Heights
Glendale
Bookwright
Fountain
Silver Hill
Leach Mill
Philadelphia
Cheek Bend
Hopewell Ch
Central Ch
Edmondson Bridge
Park Union
Strip mines
Norton Cem
Lebanon Cem
Pumping sta
Cheek Bridge
Marshall
The Sheep Neck
Anes
Rock
Duck
Long Tom Br
Scribner
Scribners Mill Bridge
Bethany Ch
Cave Spring
Brush
Culleoka
Friendship Ch
Smyrna Ch
Haynes Cem
Bryant Station
River Creek
Berlin
Berlin Spring
Verona
Berea Ch
Oslin
Dam
Caney Spring
Allen Cem
Ford
East Branch
Creek
Silo
Mile 140
Mile 145
Mile 150
Mile 155
Mile 160
Mile 165
Mile 170
Mile 175
Mile 180
Mile 0
Mile 5
Mile 10
Mile 15
Mile 20
500 Kv
46 Kv
TVA
BOUNDARY APPROXIMATE

EXHIBIT 12

DRILLING SUMMARY

Hole Number	Surface Elevation	Top of Rock, Elevation	Bottom of Serious Weathering, Elevation	Bottom of Hole, Elevation
J-14+00	899.2	894.2	887.0	684.7
J-14+00, 45°W	899.2	897.8	893.4	824.0
J-18+00	802.5	795.9	779.1	666.2
J-18+00, 45°E	802.5	802.5	802.5	703.4
J-18+00, 45°W	802.5	795.4	789.4	702.3
J-22+00	810.3	799.4	799.4	679.3
J-22+00, 45°E	810.3	799.7	778.8	728.7
J-22+00, 45°W	810.3	799.7	799.7	728.9
J-26+00	826.4	814.4	814.4	576.4
J-26+00, 45°E	826.4	813.4	811.7	742.6
J-26+00, 45°W	826.4	814.7	812.5	744.1
J-30+00	837.2	825.1	825.1	679.6
J-30+00, 45°E	837.2	824.8	824.8	753.5
J-30+00, 45°W	837.2	824.7	824.7	753.6
J-38+00	845.6	833.9	829.0	727.3
J-38+00, 45°E	845.6	833.1	822.0	763.6
J-38+00, 45°W	845.6	830.4	830.4	759.3
J-42+00	908.4	891.7	888.7	742.4
J-42+00, 45°E	908.4	895.5	893.4	823.4
L-12+00	1027.5	952.5	948.0	700.0
L-14+00	875.1	873.6	866.0	575.1
L-14+00, 45°W	875.1	875.1	871.4	692.5
L-15+00	817.1	804.2	802.9	679.6
L-15+00, 45°W	817.1	809.3	805.7	706.5
L-16+36, 45°W	795.6	785.0	785.0	700.5
L-16+38, 45°E	795.6	784.0	784.0	700.0
L-17+10, 45°W	792.7	785.3	781.7	679.3
L-17+20, 45°E	792.7	780.6	780.6	679.6
L-18+00	795.3	783.5	775.9	693.5
L-18+00, 45°E	795.3	781.2	781.2	683.7
L-18+00, 45°W	795.3	779.6	779.6	681.5
L-19+00	813.2	801.2	801.2	696.4
L-19+00, 45°E	813.2	802.6	787.4	692.1
L-19+00, 45°W	813.2	799.8	797.8	701.2
L-21+00	810.0	798.4	760.2	683.0
L-21+00, 45°E	810.0	798.7	780.3	727.2
L-21+00, 45°W	810.0	801.2	800.6	730.1
L-23+00, 45°E	810.8	802.1	802.1	731.1
L-23+00, 45°W	810.8	802.4	802.4	731.5
L-24+00	812.7	804.2	804.2	675.2
L-24+00, 45°E	812.7	803.5	802.0	732.7
L-24+00, 45°W	812.7	803.6	803.6	732.3
L-25+00, 45°E	814.9	805.2	780.8	734.0
L-25+00, 45°W	814.9	802.4	802.4	731.5
L-26+00, 45°E	816.5	806.7	806.7	735.1
L-26+00, 45°W	816.5	807.4	807.4	730.0
L-27+00	818.3	806.8	806.8	661.8
L-27+00, 45°E	818.3	807.5	807.5	730.8
L-27+00, 45°W	818.3	806.4	806.4	735.1
L-28+00, 45°E	820.3	807.4	807.4	736.7
L-28+00, 45°W	820.3	811.0	808.3	739.9
L-29+00, 45°E	823.3	811.3	811.3	740.0
L-29+00, 45°W	823.3	809.4	809.4	738.6
L-30+00	826.3	812.2	812.2	666.9
L-30+00, 45°E	826.3	810.0	810.0	738.7
L-30+00, 45°W	826.3	815.5	815.5	744.9
L-31+00, 45°E	826.7	818.4	818.4	747.7
L-31+00, 45°W	826.7	818.1	818.1	747.1
L-33+00	827.4	813.3	811.4	660.8
L-33+00, 45°E	827.4	812.6	806.0	741.9
L-33+00, 45°W	827.4	817.5	782.6	746.5
L-34+00, 45°E	842.2	829.6	820.2	758.0
L-34+00, 45°W	842.2	825.7	751.2	747.1
L-35+00, 45°E	849.3	837.8	824.6	766.6
L-35+00, 45°W	849.3	836.1	824.0	764.5
L-36+00	845.2	840.0	831.3	698.2
L-36+00, 45°E	845.2	841.5	831.9	770.7
L-36+00, 45°W	845.2	829.9	800.5	756.8
L-38+00, 45°E	843.2	830.5	824.4	757.7
L-38+00, 45°W	843.2	829.1	821.9	756.4
L-39+00	851.4	842.9	837.3	716.9
L-39+00, 45°E	851.4	840.5	834.8	768.6
L-39+00, 45°W	851.4	841.5	835.4	770.7
L-40+00, 45°E	868.6	866.3	853.4	794.5
L-41+00	890.4	874.6	860.1	722.4
L-41+00, 45°E	890.4	874.5	837.8	801.8
N-14+00	859.2	853.7	847.7	673.2
N-14+00, 45°W	859.2	854.0	849.7	699.3
N-18+00	796.0	786.6	777.2	655.0
N-18+00, 45°E	796.0	785.1	774.5	691.5
N-18+00, 45°W	796.0	785.3	785.3	689.1
N-22+00	812.8	804.8	754.1	685.8
N-22+00, 45°E	812.8	804.0	780.9	732.1
N-22+00, 45°W	812.8	804.3	804.3	731.5
N-26+00	814.2	805.2	805.2	668.2
N-26+00, 45°E	814.2	805.7	805.7	733.3
N-26+00, 45°W	814.2	805.9	805.9	734.7
N-30+00	818.2	803.8	746.0	655.1
N-30+00, 45°E	818.2	802.9	802.9	731.3
N-30+00, 45°W	818.2	805.5	805.5	734.7
N-34+00	836.8	820.8	820.8	680.4
N-34+00, 45°E	836.8	820.9	820.9	738.8
N-34+00, 45°W	836.8	819.1	819.1	749.8
N-38+23	842.8	833.7	833.7	735.8
N-38+23, 45°W	842.8	833.1	814.8	785.9
N-40+00	863.0	860.3	850.1	726.5
P-41+00	876.2	875.5	872.4	729.7
R-2+00	884.6	874.1	874.1	774.1
R-41+82	894.1	893.1	891.1	732.6
T-4+00	906.2	892.2	892.2	779.7
T-43+00	855.5	854.0	845.7	729.5
U-6+00	932.1	921.6	921.6	779.1
U-6+00, 45°E	932.1	927.1	926.3	855.0
V-8+00	952.8	946.8	944.9	800.8
V-8+00, 45°N	952.8	945.7	945.7	874.4
X-8+00	953.2	931.2	931.2	789.7
X-8+00, 45°S	953.2	938.7	936.4	866.5
X-10+00	907.9	898.7	895.9	781.9
X-10+00, 45°W	907.9	897.9	897.9	826.9
Z-12+00	889.0	872.0	867.5	787.0



NOTES:

1. *Topography based on enlargement of Kelsh topography, Dwg Nos MS-461 P 746-401 & 402.*
2. *Tennessee state system of rectangular coordinates.*
3. *Contour interval is 10'.*

REFERENCE DRAWINGS:

W-GE-1-822N1744-1, -2.....GEOLOGIC SECTIONS

LEGEND:

- *Vertical core drill hole*
- *Angle core drill hole*
- *Vertical and angle core drill holes*

Scale 200 0 200 400 Feet

NORMANDY UNIT
DUCK RIVER-MILE 248.6

SITE TOPOGRAPHY LOCATION AND SUMMARY OF DRILLING

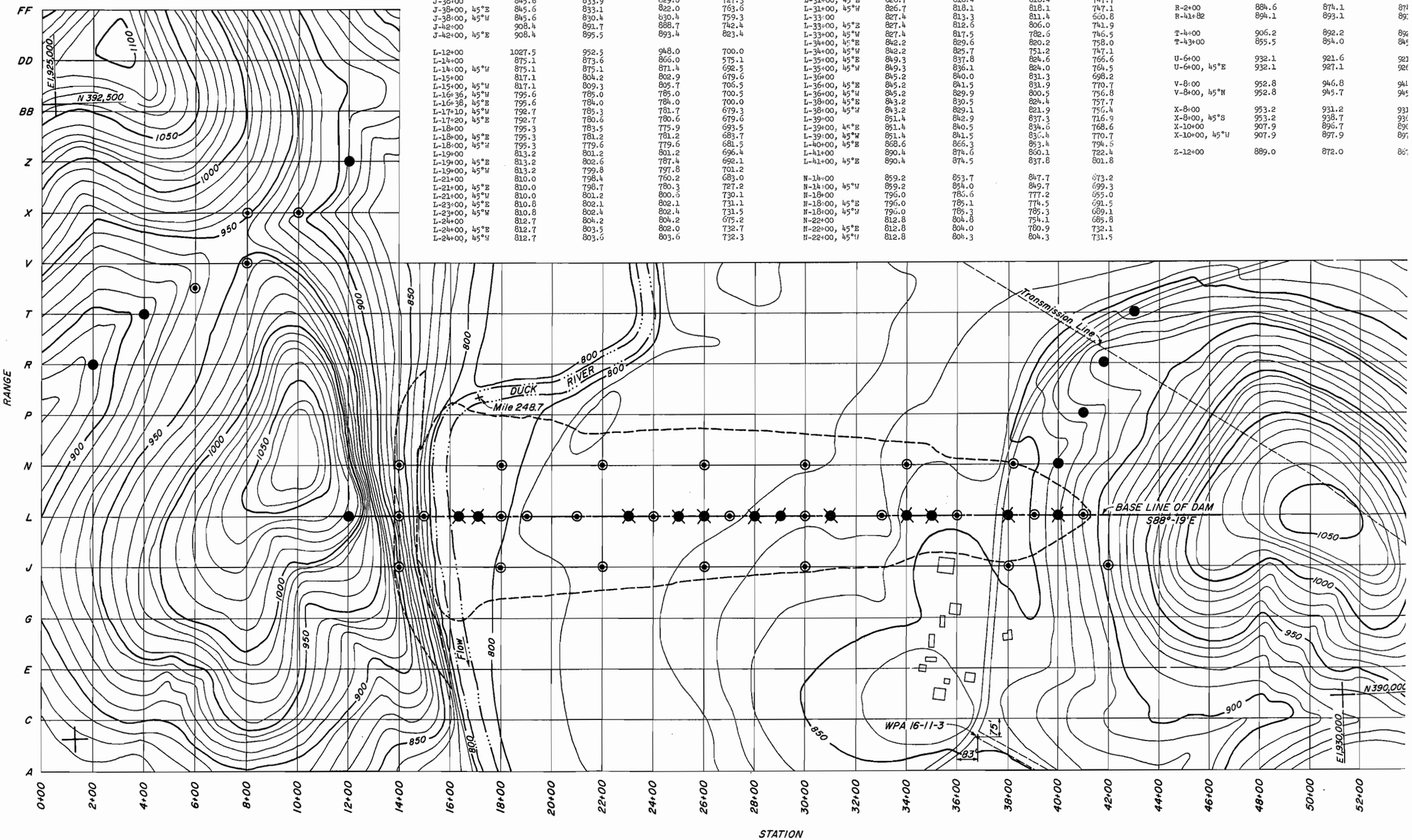
DUCK RIVER PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING

SUBMITTED	RECOMMENDED	APPROVED
J. L. Ferguson	Bert Mattson	R. L. Elliott

KNOXVILLE	4-10-68	W	PP	1	822M1740

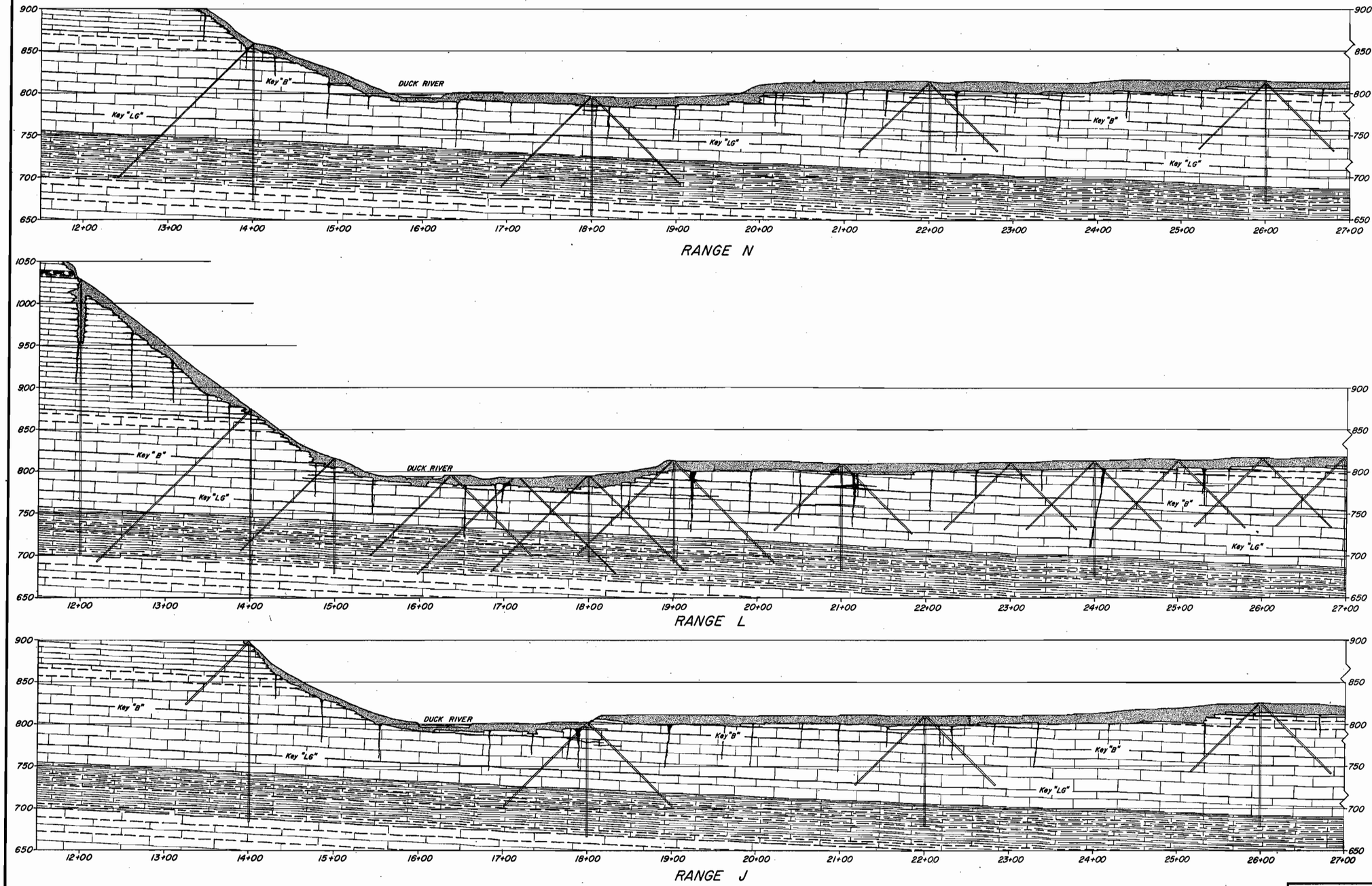
DRILLING SUMMARY

Hole Number	Surface Elevation	Top of Rock, Elevation	Bottom of Serious Weathering, Elevation	Bottom of Hole, Elevation
J-14+00	899.2	894.2	887.0	684.7
J-14+00, 45°W	899.2	897.8	893.4	824.0
J-18+00	802.5	795.9	779.1	666.2
J-18+00, 45°E	802.5	802.5	802.5	703.4
J-18+00, 45°W	802.5	795.4	789.4	702.3
J-22+00	810.3	799.4	799.4	679.3
J-22+00, 45°E	810.3	799.7	778.8	728.7
J-22+00, 45°W	810.3	799.7	799.7	728.9
J-26+00	826.4	814.4	814.4	676.4
J-26+00, 45°E	826.4	813.4	811.7	742.6
J-26+00, 45°W	826.4	814.7	812.5	744.1
J-30+00	837.2	825.1	825.1	679.6
J-30+00, 45°E	837.2	824.8	824.8	753.5
J-30+00, 45°W	837.2	824.7	824.7	753.6
J-38+00	845.6	833.9	829.0	727.3
J-38+00, 45°E	845.6	833.1	822.0	763.6
J-38+00, 45°W	845.6	830.4	830.4	759.3
J-42+00	908.4	891.7	888.7	742.4
J-42+00, 45°E	908.4	895.5	893.4	823.4
L-12+00	1027.5	952.5	948.0	700.0
L-14+00	875.1	873.6	866.0	575.1
L-14+00, 45°W	875.1	871.4	871.4	692.5
L-15+00	817.1	804.2	802.9	679.6
L-15+00, 45°W	817.1	809.3	805.7	706.5
L-16+36, 45°W	795.6	785.0	785.0	700.5
L-16+38, 45°E	795.6	784.0	784.0	700.0
L-17+10, 45°W	792.7	785.3	781.7	679.3
L-17+20, 45°E	792.7	780.6	780.6	679.6
L-18+00	795.3	783.5	775.9	693.5
L-18+00, 45°E	795.3	781.2	781.2	683.7
L-18+00, 45°W	795.3	779.6	779.6	681.5
L-19+00	813.2	801.2	801.2	696.4
L-19+00, 45°E	813.2	802.6	787.4	692.1
L-19+00, 45°W	813.2	799.8	797.8	701.2
L-21+00	810.0	798.4	760.2	683.0
L-21+00, 45°E	810.0	798.7	780.3	727.2
L-21+00, 45°W	810.0	801.2	800.6	730.1
L-23+00, 45°E	810.8	802.1	802.1	731.1
L-23+00, 45°W	810.8	802.4	802.4	731.5
L-24+00	812.7	804.2	804.2	675.2
L-24+00, 45°E	812.7	803.5	802.0	732.7
L-24+00, 45°W	812.7	803.6	803.6	732.3
L-25+00, 45°E	814.9	805.2	780.8	734.0
L-25+00, 45°W	814.9	802.4	802.4	731.5
L-26+00, 45°E	816.5	806.7	806.7	735.1
L-26+00, 45°W	816.5	807.4	807.4	736.0
L-27+00	818.3	806.8	806.8	661.8
L-27+00, 45°E	818.3	807.5	807.5	736.8
L-27+00, 45°W	818.3	806.4	806.4	735.1
L-28+00, 45°E	820.3	807.4	807.4	736.7
L-28+00, 45°W	820.3	811.0	808.3	739.9
L-29+00, 45°E	823.3	811.3	811.3	740.0
L-29+00, 45°W	823.3	809.4	809.4	738.6
L-30+00	826.3	812.2	812.2	666.9
L-30+00, 45°E	826.3	810.0	810.0	738.7
L-30+00, 45°W	826.3	815.5	815.5	744.9
L-31+00, 45°E	826.7	818.4	818.4	747.7
L-31+00, 45°W	826.7	818.1	818.1	747.1
L-33+00	827.4	813.3	811.4	660.8
L-33+00, 45°E	827.4	812.6	806.0	741.9
L-33+00, 45°W	827.4	817.5	782.6	746.5
L-34+00, 45°E	842.2	829.6	820.2	758.0
L-34+00, 45°W	842.2	825.7	751.2	747.1
L-35+00, 45°E	849.3	837.8	824.6	766.6
L-35+00, 45°W	849.3	836.1	824.0	764.5
L-36+00	845.2	840.0	831.3	698.2
L-36+00, 45°E	845.2	841.5	831.9	770.7
L-36+00, 45°W	845.2	829.9	800.5	756.8
L-38+00, 45°E	843.2	830.5	824.4	757.7
L-38+00, 45°W	843.2	829.1	821.9	756.4
L-39+00	851.4	842.9	837.3	716.9
L-39+00, 45°E	851.4	840.5	834.6	768.6
L-39+00, 45°W	851.4	841.5	836.4	770.7
L-40+00, 45°E	868.6	866.3	863.4	794.5
L-41+00	890.4	874.6	860.1	722.4
L-41+00, 45°E	890.4	874.5	837.8	801.8
N-14+00	859.2	853.7	847.7	673.2
N-14+00, 45°W	859.2	854.0	849.7	699.3
N-18+00	796.0	786.6	777.2	655.0
N-18+00, 45°E	796.0	785.1	774.5	691.5
N-18+00, 45°W	796.0	785.3	785.3	689.1
N-22+00	812.8	804.8	754.1	685.8
N-22+00, 45°E	812.8	804.0	780.9	732.1
N-22+00, 45°W	812.8	804.3	804.3	731.5
N-26+00	814.2	805.2		80
N-26+00, 45°E	814.2	805.7		80
N-26+00, 45°W	814.2	805.9		80
N-30+00	818.2	803.8		74
N-30+00, 45°E	818.2	802.9		80
N-30+00, 45°W	818.2	805.5		80
N-34+00	836.8	820.8		82
N-34+00, 45°E	836.8	820.9		82
N-34+00, 45°W	836.8	819.1		81
N-38+23	842.8	833.7		83
N-38+23, 45°W	842.8	833.1		81
N-40+00	863.0	860.3		85
F-41+00	876.2	875.5		87
R-2+00	884.6	874.1		87
R-41+82	894.1	893.1		89
T-4+00	906.2	892.2		89
T-43+00	855.5	854.0		84
U-6+00	932.1	921.6		92
U-6+00, 45°E	932.1	927.1		92
V-8+00	952.8	946.8		94
V-8+00, 45°W	952.8	945.7		94
X-8+00	953.2	931.2		93
X-8+00, 45°S	953.2	938.7		93
X-10+00	907.9	896.7		89
X-10+00, 45°W	907.9	897.9		89
Z-12+00	889.0	872.0		86



REV NO.	DATE	MADE	CHKD	SUPV	INSP
DRWN REH		COMPUTED			
TRCD		ENGINEER D.B. Cagle			
CHKD					

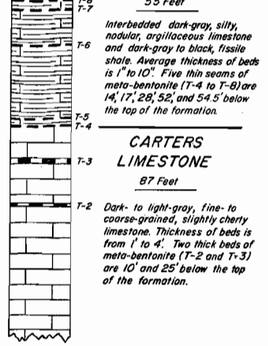
EXHIBIT 13



RANGE N

RANGE L

RANGE J



CATHEYS FORMATION
150+ Feet

Fine- to medium-grained, medium to dark-gray, thin bedded limestone with bands of blue-gray shale. Average thickness of beds is 8".

CANNON LIMESTONE
117 Feet

Fine- to medium-grained, dark- to medium-gray limestone. Average thickness of beds is 1'. Key bed "B" is a one foot thick bed of prominently banded limestone. Key bed "LG" is a one foot bed of very light gray limestone. Two thin seams of meta-bentonite (T-9 and T-10) occur 4 and 14 feet below the top of the formation.

HERMITAGE FORMATION
55 Feet

Interbedded dark-gray, silty, nodular, argillaceous limestone and dark-gray to black, fissile shale. Average thickness of beds is 1" to 10". Five thin seams of meta-bentonite (T-4 to T-8) are 14', 17', 28', 52', and 54.5' below the top of the formation.

CARTERS LIMESTONE
87 Feet

Dark- to light-gray, fine- to coarse-grained, slightly cherty limestone. Thickness of beds is from 1' to 4'. Two thick beds of meta-bentonite (T-2 and T-3) are 10' and 25' below the top of the formation.

STRATIGRAPHIC COLUMN

Scale: 50 0 50 100 Feet

LEGEND:

- OVERBURDEN - Alluvium and Residuum
- CATHEYS FORMATION
- CANNON LIMESTONE
- HERMITAGE FORMATION
- CARTERS LIMESTONE

NOTES:

1. For geologic sections from station 27+00 to station 42+00 see companion drawing W GE I 822 N 1744-2.
2. For location of drill holes see drawing W PP I 822 M 1740.

REV NO.	DATE	MADE	CHKD	SUPV	INSP
DRWN		COMPUTED			
TRCD		ENGINEER			
CHKD					

NORMANDY UNIT
DUCK RIVER-MILE 248.6

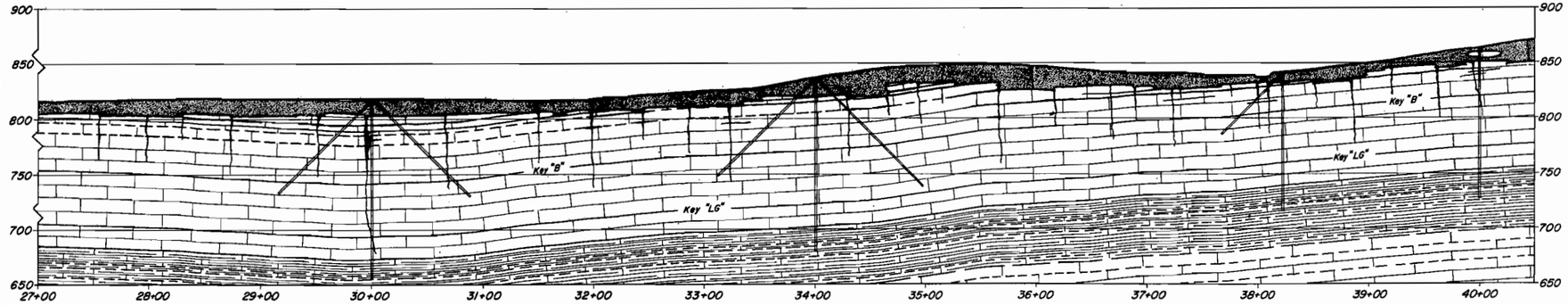
GEOLOGIC SECTIONS
(STA. 12+00 TO STA. 27+00)

DUCK RIVER PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING

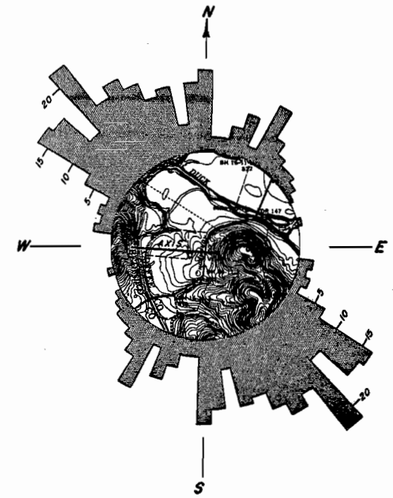
SUBMITTED	RECOMMENDED	APPROVED
R. A. Parker	John M. Kelley	Herbert S. Marsh

KNOXVILLE	4-17-68	W	GE	I	822N1744-1

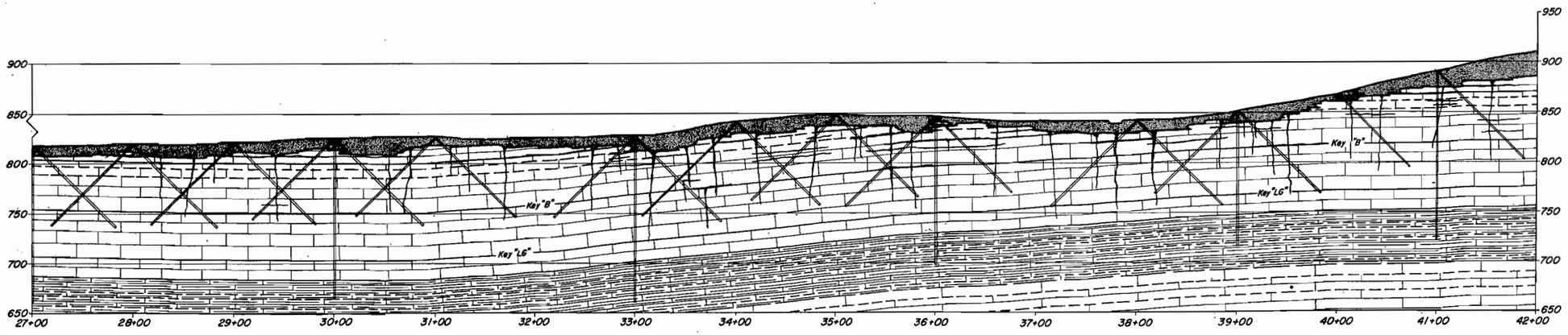
EXHIBIT 14



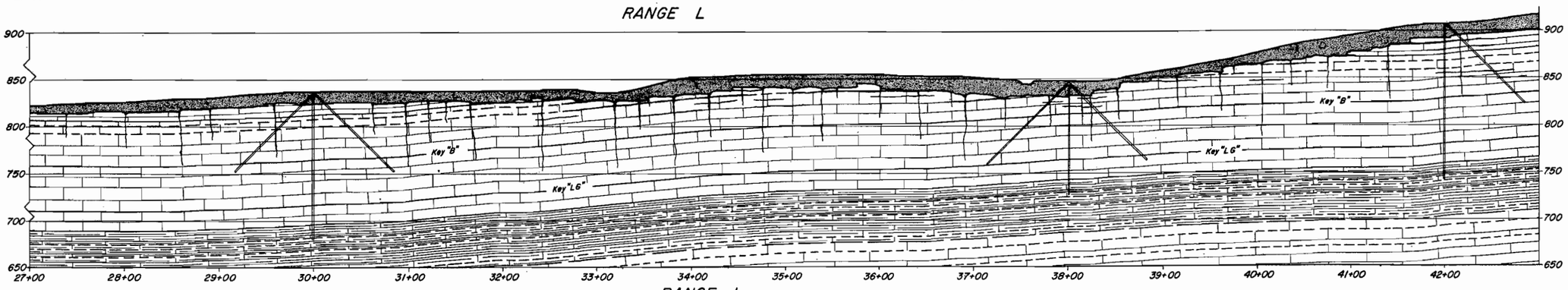
RANGE N



JOINT DIAGRAM
(See Note 3)



RANGE L



RANGE J

LEGEND:

- OVERBURDEN – Alluvium and Residuum
- CATHEYS FORMATION
- HERMITAGE FORMATION
- CANNON LIMESTONE
- CARTERS LIMESTONE

NOTES:

1. For geologic sections from station 12+00 to station 27+00 see companion drawing W GE I 822 N 1744-1.
2. For location of drill holes see drawing W PP I 822 M 1740.
3. The orientation of high angle joints was measured in cores from angled drill holes. On the joint diagram the number of joints for each 5° of azimuth is plotted

Scale:
50 0 50 100 Feet

KEY NO.	DATE	MADE	CHKD	SUPV	INSP
DRWN		COMPUTED			
TRCD		ENGINEER			
CHKD					

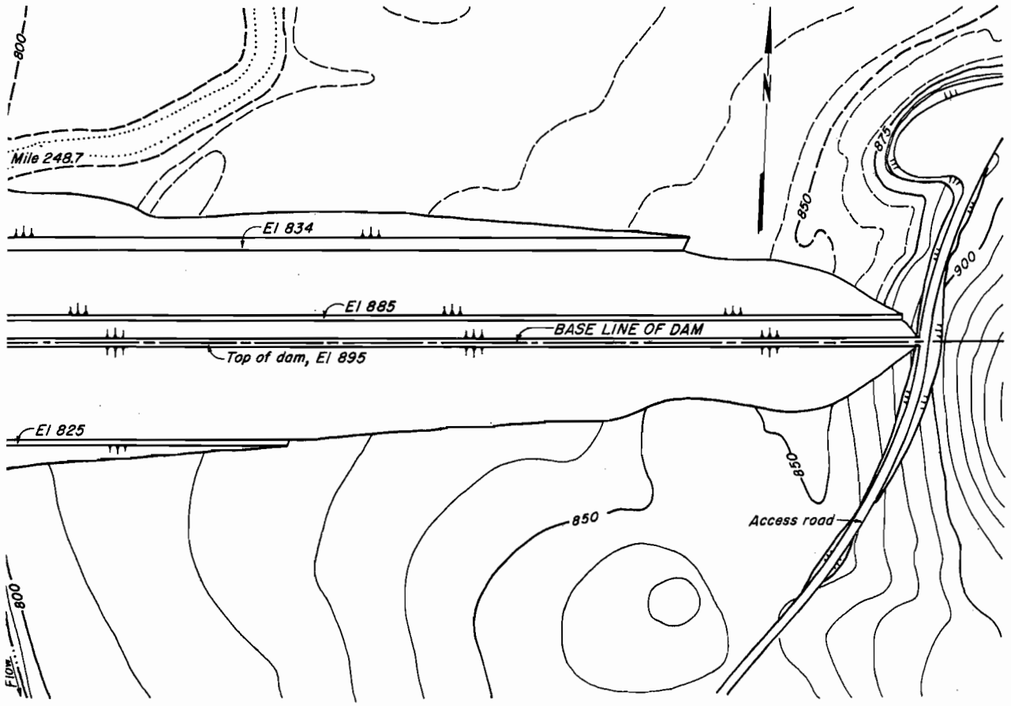
NORMANDY UNIT
DUCK RIVER-MILE 248.6

GEOLOGIC SECTIONS
(STA. 27+00 TO STA. 42+00)

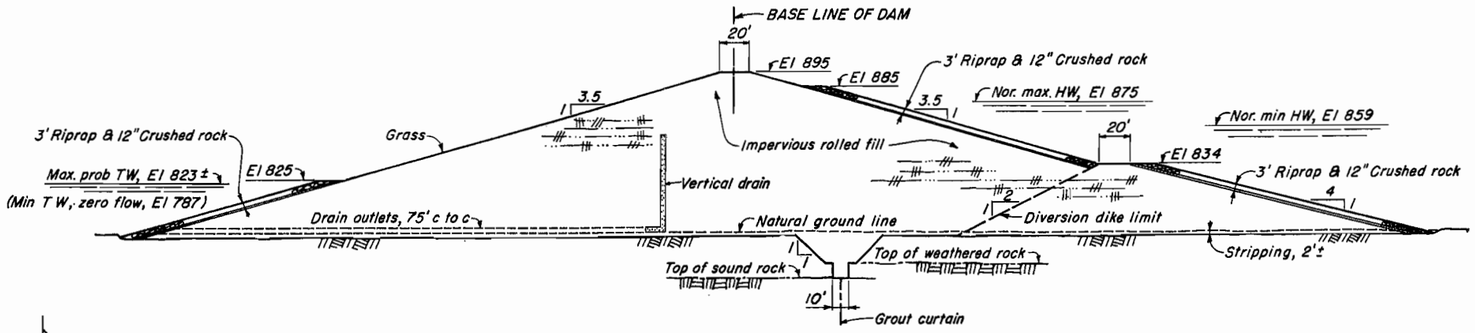
DUCK RIVER PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING

SUBMITTED	RECOMMENDED	APPROVED
P. R. Parker	John M. Kelley	Borden C. Morgander

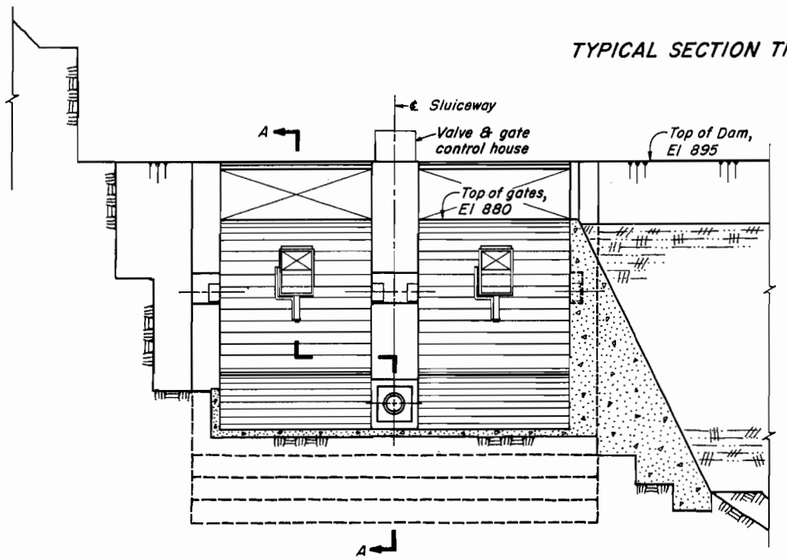
KNOXVILLE	4-17-68	W	GE	I	822 N 1744-2



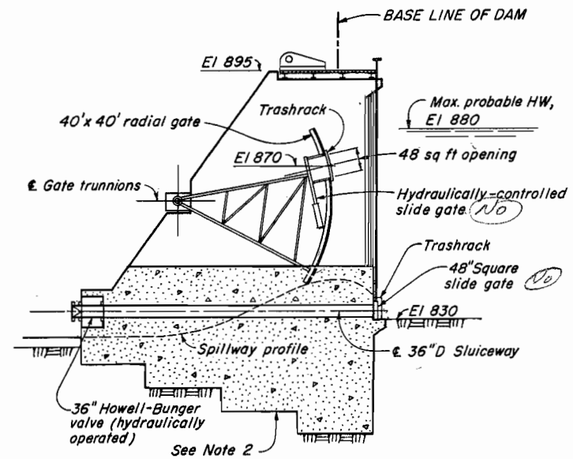
GENERAL PLAN



TYPICAL SECTION THRU DAM

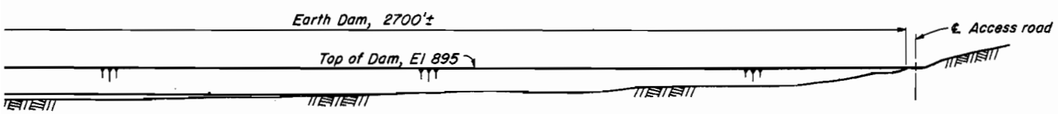


DOWNSTREAM ELEVATION

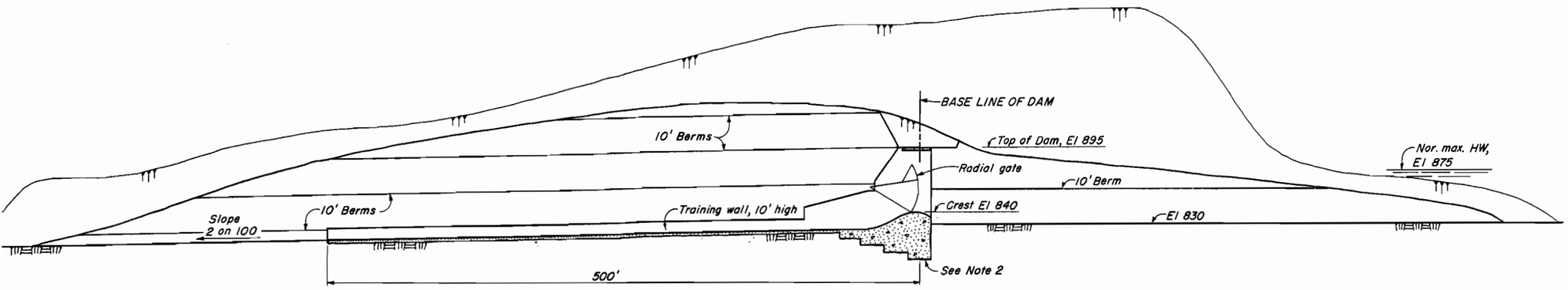


SECTION A-A

SPILLWAY
SHOWING SLUICEWAY THRU PIER



DOWNSTREAM ELEVATION



LONGITUDINAL SECTION THRU SPILLWAY

NOTES:
1. Topography taken from Kelsh topography, Dwg No. G-MS-461 P 746-401 & 402.
2. Depth of excavation to be determined by foundation conditions.

Scale 200 0 200 400 Feet
GENERAL PLAN & DOWNSTREAM ELEVATION

Scale 50 0 50 100 Feet
TYPICAL SECTION THRU DAM & LONGITUDINAL SECTION THRU SPILLWAY

Scale 20 0 20 40 Feet
SPILLWAY

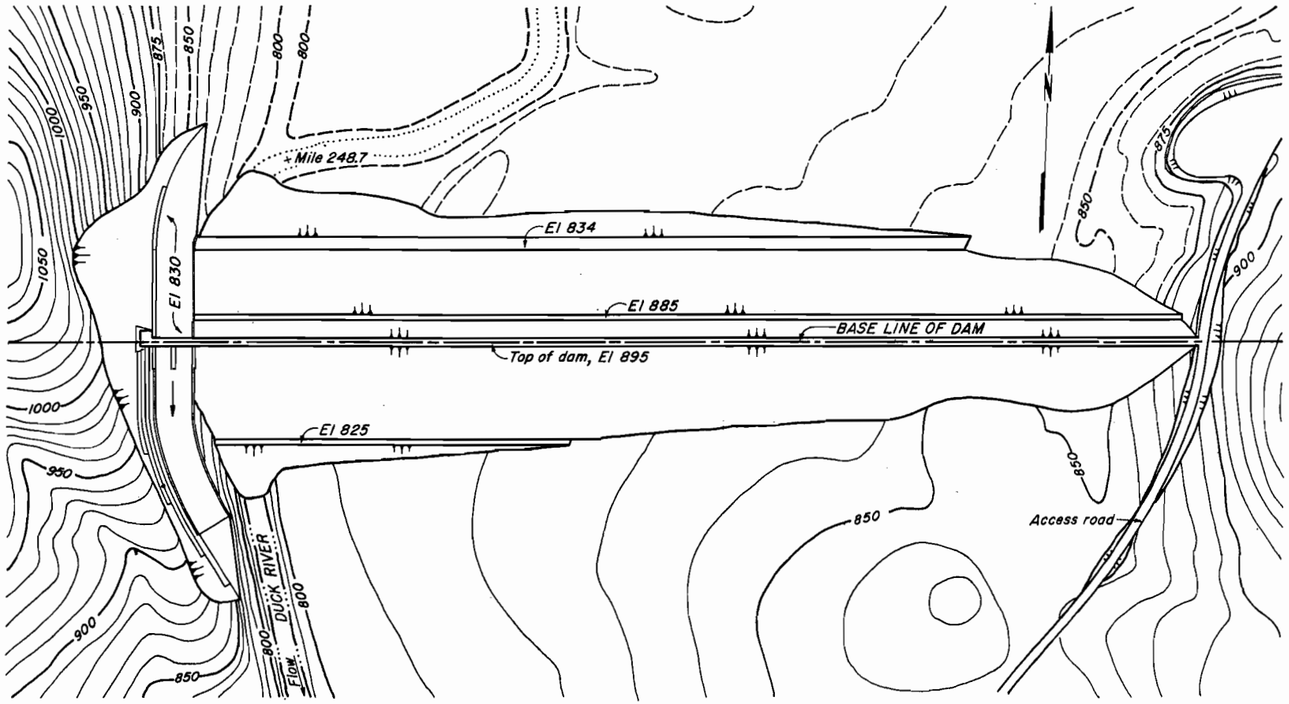
NORMANDY UNIT
DAM & SPILLWAY

PLAN, ELEVATION AND SECTIONS

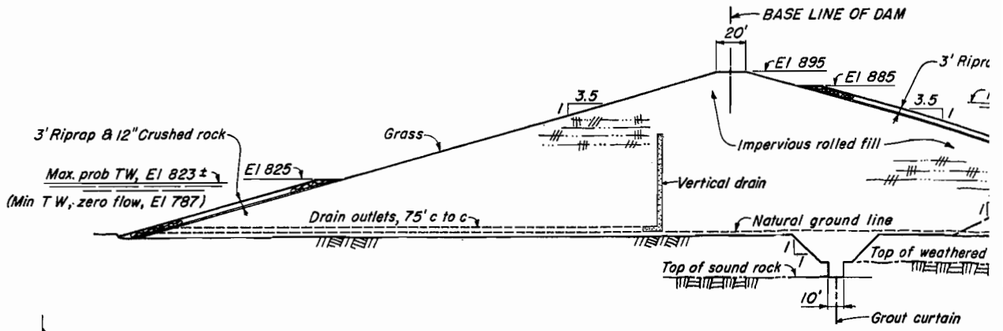
DUCK RIVER PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING

SUBMITTED	RECOMMENDED	APPROVED
J. L. Ingmire	Dan H. Mathews	R. E. Elliott

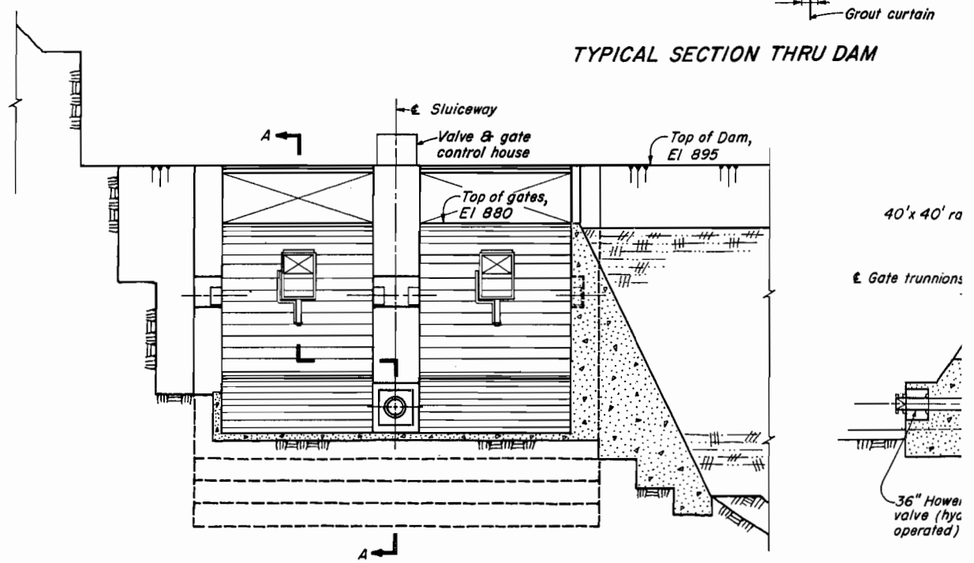
KNOXVILLE	6-27-68	W	PP	1	121L168



GENERAL PLAN

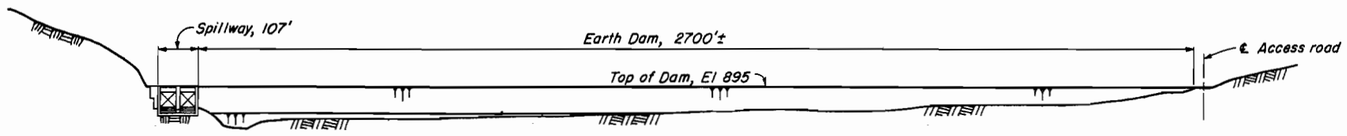


TYPICAL SECTION THRU DAM

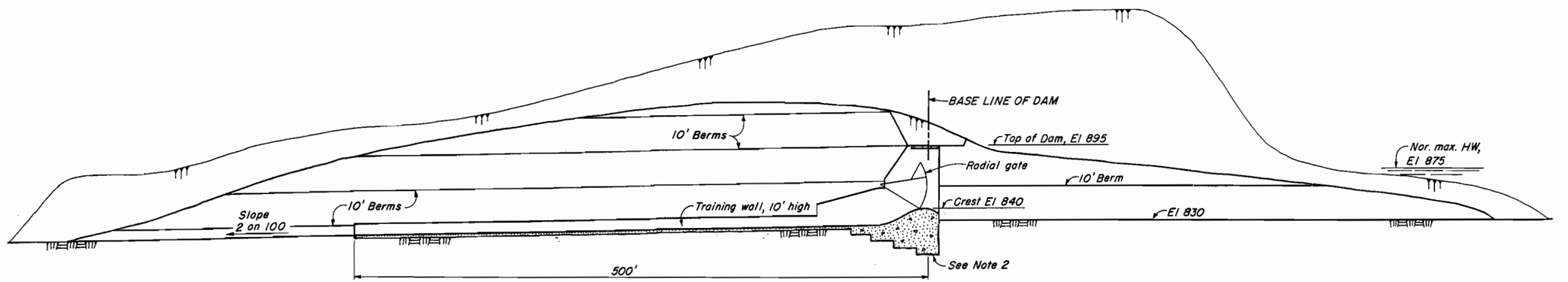


DOWNSTREAM ELEVATION

SPILLWAY
SHOWING SLUICEWAY THRU PIER



DOWNSTREAM ELEVATION



LONGITUDINAL SECTION THRU SPILLWAY

REV NO.	DATE	MADE	CHKD	SUPV	INSP
DRWN. REH		COMPUTED			
TRCD.		ENGINEER			
CHKD.		H.C. Whitley			

EXHIBIT 16

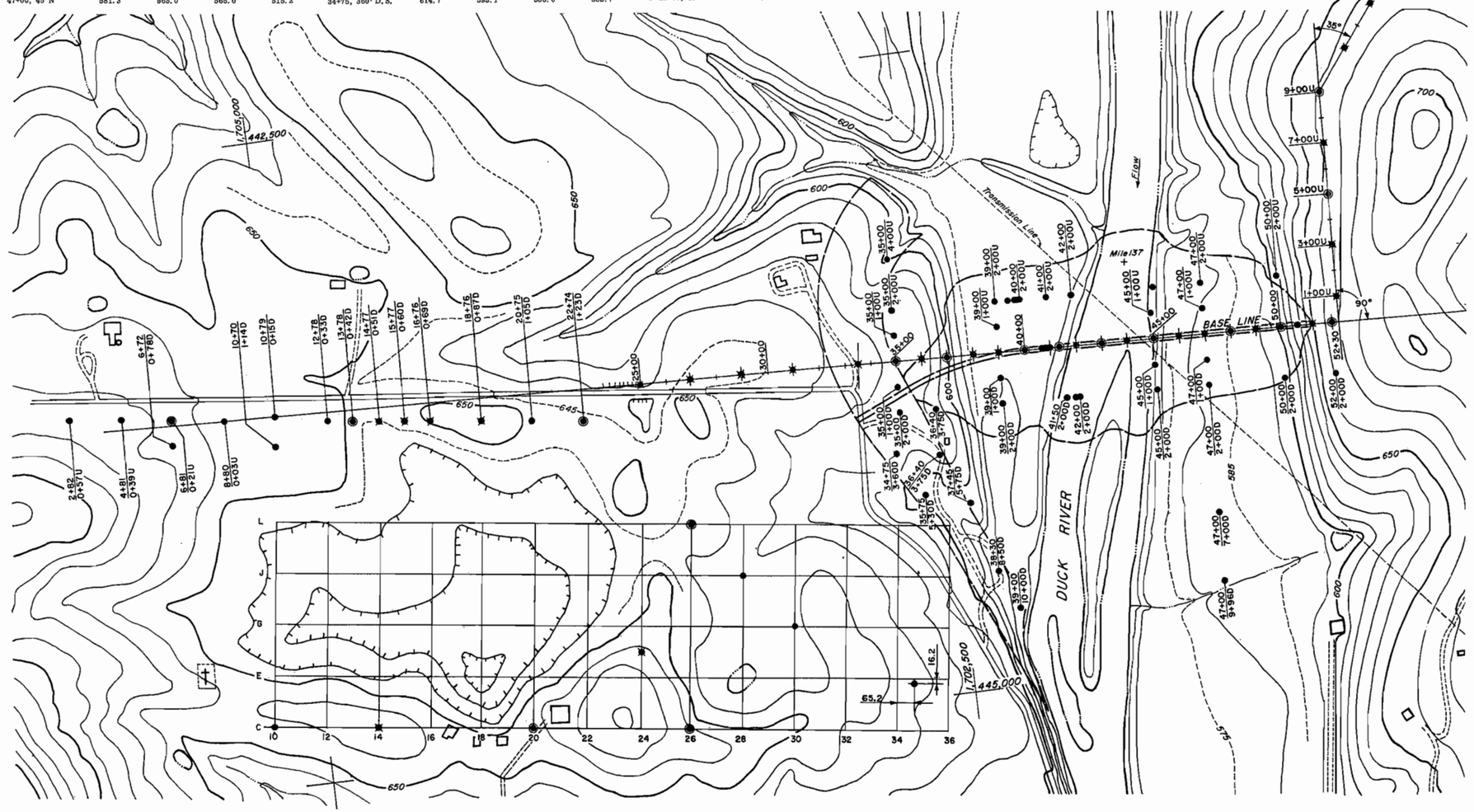
DRILLING SUMMARY

Hole Number	Surface Elevation	Top of Rock, Elevation	Bottom of Serious Weathering, Elevation	Bottom of Hole, Elevation
Main Dam				
25+00, 45°E	637.1	626.5	625.6	606.4
25+00, 45°W	637.1	629.8	610.0	604.9
27+00, 45°E	647.3	615.3	615.3	601.9
27+00, 45°W	647.3	616.1	611.1	599.2
29+00, 45°E	644.0	628.5	613.3	605.3
29+00, 45°W	644.0	621.7	621.7	601.8
31+00, 45°E	643.7	623.3	610.7	596.0
31+00, 45°W	643.7	618.8	608.4	601.8
33+52, 45°E	633.4	617.5	594.5	586.5
33+52, 45°W	633.4	613.0	602.3	583.4
35+00	628.4	600.4	586.4	451.6
35+00, 45°W	628.4	604.5	602.9	547.2
36+00, 45°E	623.1	603.7	603.7	532.5
36+00, 45°W	623.1	607.9	607.9	537.1
37+00	595.1	593.1	585.4	477.1
37+00, 45°E	595.1	594.4	591.6	537.3
38+00, 45°E	569.3	550.2	546.7	478.9
38+00, 45°W	569.3	538.2	522.6	467.5
39+00, 45°E	570.2	539.3	539.3	468.4
39+00, 45°W	570.2	539.4	478.4	468.4
39+00, 45°N	570.2	538.2	538.2	482.5
39+00, 45°S	570.2	537.4	537.4	482.9
40+00	572.4	538.9	448.6	436.2
40+00, 45°E	572.4	536.5	487.6	466.6
40+00, 45°W	572.4	537.8	509.0	466.6
40+64	571.2	540.7	494.7	481.2
40+75	570.6	540.6	507.6	470.6
40+85	571.2	542.5	506.7	401.2
41+00	569.0	540.5	526.0	493.0
41+33.2	569.9	542.1	542.1	443.9
41+33.2, 45°E	569.9	541.0	508.6	468.8
41+33.2, 45°W	569.9	542.8	503.7	471.3
42+00, 45°E	557.9	541.4	532.4	472.4
42+00, 45°W	558.2	542.5	504.0	472.7
43+00	557.3	540.6	532.3	461.5
43+00, 45°E	559.7	543.2	527.9	473.1
43+00, 45°W	559.1	541.9	514.1	472.6
44+00, 45°E	558.2	540.5	537.9	469.8
44+00, 45°W	558.8	541.5	504.8	472.7
45+00	566.8	554.2	502.4	404.2
45+00, 45°E	565.8	541.5	538.1	502.2
45+00, 45°W	567.6	562.3	561.2	508.2
46+00, 45°E	579.6	562.3	561.9	514.2
46+00, 45°W	579.6	562.3	561.9	509.2
47+00, 45°E	581.3	564.9	563.6	514.6
47+00, 45°W	581.3	565.8	562.6	514.8
47+00, 45°N	581.3	565.0	565.0	515.2
47+00, 45°S	581.3	564.9	564.9	507.9
48+00	584.0	568.2	505.5	418.0
48+00, 45°E	584.0	567.2	564.2	510.5
48+00, 45°W	584.0	566.3	566.3	517.4
49+00, 45°E	591.6	567.6	556.2	517.7
49+00, 45°W	591.6	576.8	571.1	510.3
50+00	606.9	600.3	580.9	490.5
50+00, 45°W	606.9	600.0	598.4	524.6
50+65	636.0	594.3	623.3	488.5
51+21, 45°W	655.0	648.8	647.3	538.3
52+00	668.8	666.9	649.0	490.8
52+00, 45°E	668.8	658.6	646.2	542.4
35+00, 100' U.S.	639.1	607.9	607.9	597.0
39+00, 100' U.S.	569.9	538.8	538.8	483.9
45+00, 100' U.S.	566.3	553.3	533.3	500.3
47+00, 100' U.S.	580.9	566.4	530.9	494.6
35+00, 200' U.S.	625.5	610.9	602.9	486.9
39+00, 200' U.S.	569.6	540.2	532.1	477.9
39+50, 200' U.S.	570.4	539.4	506.1	484.8
39+75, 200' U.S.	570.4	539.4	506.4	484.7
39+88, 200' U.S.	570.3	537.8	506.8	485.0
40+00, 200' U.S.	570.1	536.6	531.6	484.3
41+00, 200' U.S.	572.3	539.7	532.3	476.6
42+00, 200' U.S.	568.6	541.8	501.2	480.1
45+17, 200' U.S.	572.5	561.0	561.0	496.5
47+00, 200' U.S.	575.4	564.9	553.4	489.4
50+00, 200' U.S.	613.3	611.3	605.8	495.3
35+00, 400' U.S.	601.4	596.4	594.6	585.9
35+00, 100' D.S.	616.1	594.9	590.8	584.9
39+00, 100' D.S.	570.3	538.0	517.3	484.4
45+00, 100' D.S.	575.4	563.0	521.4	498.3
47+00, 100 ' D.S.	582.9	564.6	528.5	486.9
35+00, 200' D.S.	623.9	589.7	589.7	483.4
36+40, 200' D.S.	610.2	604.2	595.2	590.2
39+00, 200' D.S.	570.4	537.8	528.4	474.2
41+50, 200' D.S.	566.9	538.4	502.6	480.9
41+85, 200' D.S.	556.9	539.9	501.9	490.9
42+00, 200' D.S.	556.8	537.2	533.3	486.8
45+00, 200' D.S.	578.6	562.9	531.0	502.3
47+03, 200' D.S.	581.6	564.6	531.1	486.6
50+00, 200' D.S.	601.5	600.5	591.0	500.5
52+00, 200' D.S.	668.2	643.7	643.7	490.7
34+75, 360' D.S.	614.7	593.1	586.6	582.7
36+40, 375' D.S.	613.3	599.8	588.4	587.3
35+75, 530' D.S.	594.1	584.1	582.1	571.1
37+45, 575' D.S.	593.1	588.5	580.3	578.1
47+00, 700' D.S.	585.4	563.8	563.8	499.1
38+30, 850' D.S.	567.4	541.4	541.4	531.4
47+00, 969' D.S.	579.9	561.4	515.3	458.9
39+00, 1000' D.S.	568.2	536.2	520.5	418.2

Right Rim

Initial Grid Designation	Hole Number	Surface Elevation	Top of Rock, Elevation	Bottom of Serious Weathering, Elevation	Bottom of Hole, Elevation
P- 2+00	2+82.13, 57.28' U.S.	676.7	672.9	672.5	572.9
P- 4+00	4+81.32, 39.29' U.S.	679.4	678.6	678.6	593.7
O- 6+00	6+71.52, 76.20' D.S.	671.4	669.4	662.6	591.7
P- 6+00	6+80.51, 21.30' U.S.	668.4	666.4	654.7	422.0
P- 8+00, 45°E	6+80.51, 21.30' U.S.	668.4	662.2	646.5	556.1
P- 8+00, 45°W	6+80.51, 21.30' U.S.	668.4	665.6	652.5	559.5
P- 8+00	8+79.70, 3.32' U.S.	660.8	652.8	652.8	595.2
O-10+00	10+69.89, 114.27' D.S.	657.4	629.9	629.4	591.7
P-10+00	10+78.89, 14.67' D.S.	658.6	652.4	629.3	400.8
P-12+00	12+78.06, 32.65' D.S.	655.8	631.0	631.0	529.4
P-13+00	13+77.68, 41.64' D.S.	651.1	630.6	630.6	595.2
P-13+00, 45°E	13+77.68, 41.64' D.S.	651.1	635.8	629.0	598.6
P-13+00, 45°W	13+77.68, 41.64' D.S.	651.1	644.1	637.2	600.1
P-14+00, 45°E	14+77.27, 50.64' D.S.	647.7	637.0	637.0	598.8
P-14+00, 45°W	14+77.27, 50.64' D.S.	647.7	636.4	626.9	605.2
P-15+00, 45°E	15+76.86, 59.63' D.S.	647.4	626.2	626.2	599.3
P-16+00, 45°E	16+76.46, 68.63' D.S.	649.8	627.3	616.6	600.3
P-16+00 45°W	16+76.46, 68.63' D.S.	649.8	642.3	617.1	600.3
P-18+00, 45°E	18+75.65, 86.61' D.S.	651.7	627.9	622.0	604.4
P-18+00, 45°W	18+75.65, 86.61' D.S.	651.7	629.1	629.1	602.2
P-20+00	20+74.84, 104.59' D.S.	648.5	624.3	624.3	372.2
P-22+00	22+74.03, 122.57' D.S.	648.9	626.7	622.9	522.6
P-22+00, 45°E	22+74.03, 122.57' D.S.	648.9	633.8	622.0	537.3
P-22+00, 45°W	22+74.03, 122.57' D.S.	648.9	631.1	625.1	525.2

Hole Number	Surface Elevation	Top of Rock, Elevation	Bottom of Serious Weathering, Elevation	Bottom of Hole, Elevation
Left Rim				
1+00U, 45°N	673.8	673.8	644.3	606.6
1+00U, 45°S	673.8	673.8	648.4	611.1
3+00U, 45°N	674.2	674.2	673.3	659.7
3+00U, 45°S	674.2	674.2	674.2	651.4
5+00U	665.8	663.1	639.8	500.1
5+00U, 45°N	665.8	658.7	643.9	603.9
5+00U, 45°S	665.8	658.6	656.7	613.6
7+00U, 45°N	664.1	662.7	640.2	611.1
7+00U, 45°S	664.1	660.1	660.1	611.8
9+00U	662.6	657.2	647.9	494.6
9+00U, 45°N	662.6	656.2	641.9	617.4
9+00U, 45°S	662.6	658.4	646.7	614.9
2+00A, 45°NE	661.9	644.2	641.8	611.0
2+00A, 45°SW	661.9	652.7	642.2	609.2
4+00A, 45°NE	660.3	650.1	650.1	612.9
4+00A, 45°SW	660.3	650.4	643.4	614.2
6+00A	658.1	653.9	651.2	501.3
6+00A, 45°NE	658.1	641.3	641.0	606.9
6+00A, 45°SW	658.1	656.5	645.1	616.4
8+00A, 45°NE	652.5	646.6	646.6	613.2
8+00A, 45°SW	652.5	650.6	647.6	617.0
9+00A, 45°NE	657.8	647.2	647.2	616.6
9+00A, 45°SW	657.8	651.8	645.6	618.3
10+00A	664.0	647.6	647.6	499.0
Initial Drilling				
C-10+00	656.6	648.1	648.1	397.7
C-14+00, 45°W	666.6	659.9	652.5	487.0
C-20+00	658.6	651.1	643.1	401.6
C-20+00, 45°E	658.6	648.7	643.5	479.0
C-26+00	665.6	649.8	648.4	395.8
C-26+00, 45°E	665.6	654.4	601.1	453.0
D-83.8, 34+65.2	635.1	601.2	601.2	358.1
F-24+00, 45°N	665.0	655.9	641.3	476.6
G-30+00	635.5	605.5	605.5	503.5
J-28+00	635.3	624.3	620.3	523.3
L-26+00	642.7	639.7	637.7	536.4
L-26+00, 45°N	642.7	638.5	611.4	533.5
L-26+00, 45°S	642.7	637.2	614.1	526.0



NOTES:
1. Topography taken from enlargment of Kelsh topography, Dwg No. G-MS-461 P746-403.
2. Contour interval 10 feet.
3. Tennessee state system of rectangular coordinates.

REFERENCE DRAWINGS:
W-GE-1-822K1657-1,2,3,4,5____GEOLOGIC SECTIONS

LEGEND:
- Vertical core drill hole
- Angle core drill hole
- Vertical and angle core drill holes

Scale 200 0 200 400 Feet

REV NO.	DATE	MADE	CHKD	SUPV	INSP
DRWN HM-DC	COMPUTED				
TRCD	ENGINEER				
CHKD DJC-DAC					

COLUMBIA UNIT
DUCK RIVER–MILE 136.9

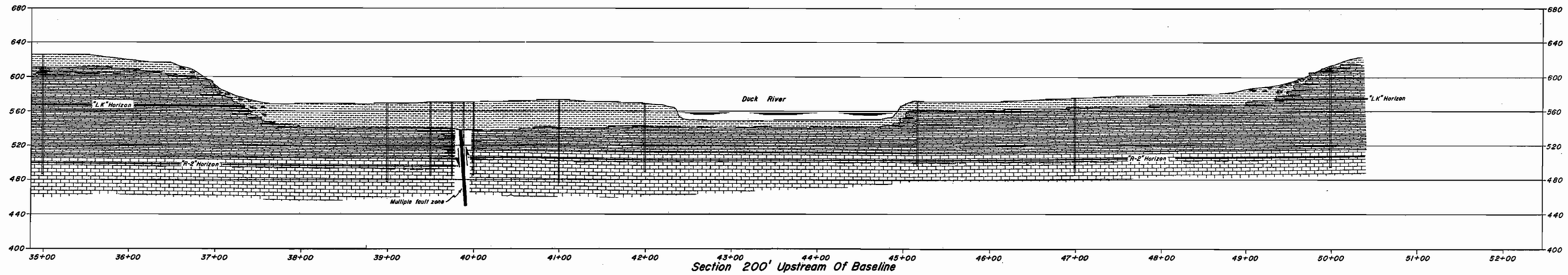
SITE TOPOGRAPHY LOCATION AND SUMMARY OF DRILLING

DUCK RIVER PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING

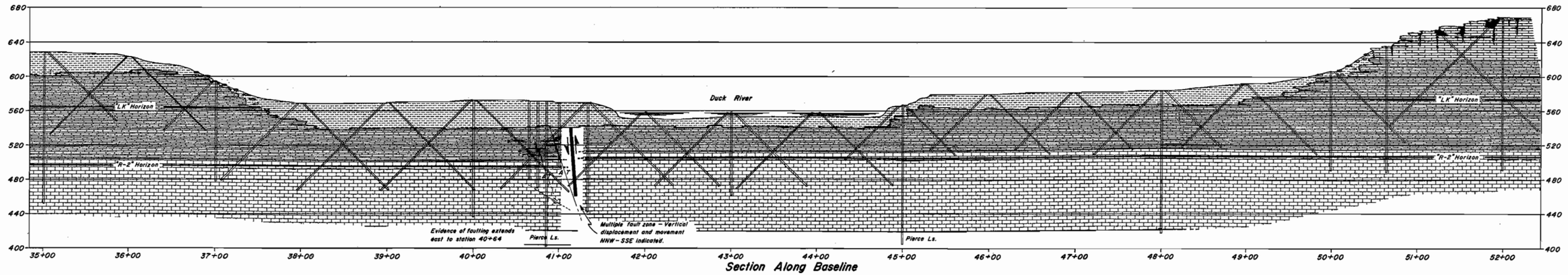
SUBMITTED	RECOMMENDED	SUBMITTED
J. L. Ferguson	Dave H. Matteson	R. G. Lee

KNOXVILLE	2-15-67	W	PP	1	461WW124R1

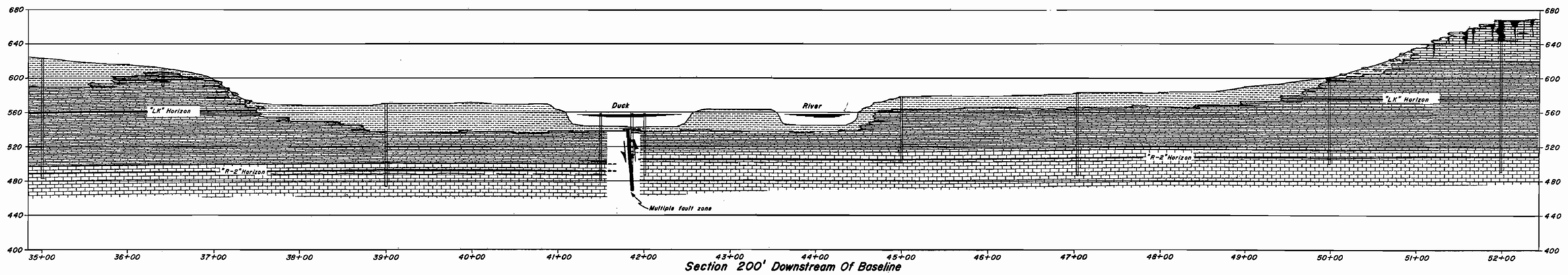
EXHIBIT 17



Section 200' Upstream Of Baseline



Section Along Baseline



Section 200' Downstream Of Baseline

LEGEND:

- Soil – Residuum / Alluvium
- Carters Formation – Light gray, coarse to fine-grained limestone.
- Lebanon Formation – Dark gray, thinly interbedded limestone and shale. "L.K" is a key shale horizon.
- Ridley Formation – Medium to light gray, fine to coarse-grained limestone. "R-2" is a key limestone horizon.

Pierce Formation – Gray limestone – 20' ±

Murfreesboro Formation – Thick-bedded limestone.

NOTES:

1. The Carters limestone exhibits many deep, joint controlled, solution cavities.
2. The Lebanon formation contains many, very thin, partially decomposed, shale horizons and a number of gypsum layers from 0.1" to 0.01" thick. From 40' to 54' and 60' to 91' below the Carters contact, the physical character of the rock will allow rapid mechanical decomposition on exposure.
3. The Ridley limestone contains a very persistent 0.1' bedding plane cavity, partially clay filled, at approximately 3.0' below the "R-2" horizon.
4. The zone of major vertical displacement associated with the fault is indicated on the sections; however, additional secondary faults with vertical and horizontal displacement and associated weathering will be encountered, principally to the east.
5. Only features of major weathering are indicated on these sections.
6. For drill hole location, see drawing W PP I 461WW124A-1.
7. For sections on rims, see companion drawings.

SCALE: 40 0 40 80 120 Feet

COLUMBIA UNIT
DUCK RIVER – MILE 136.9

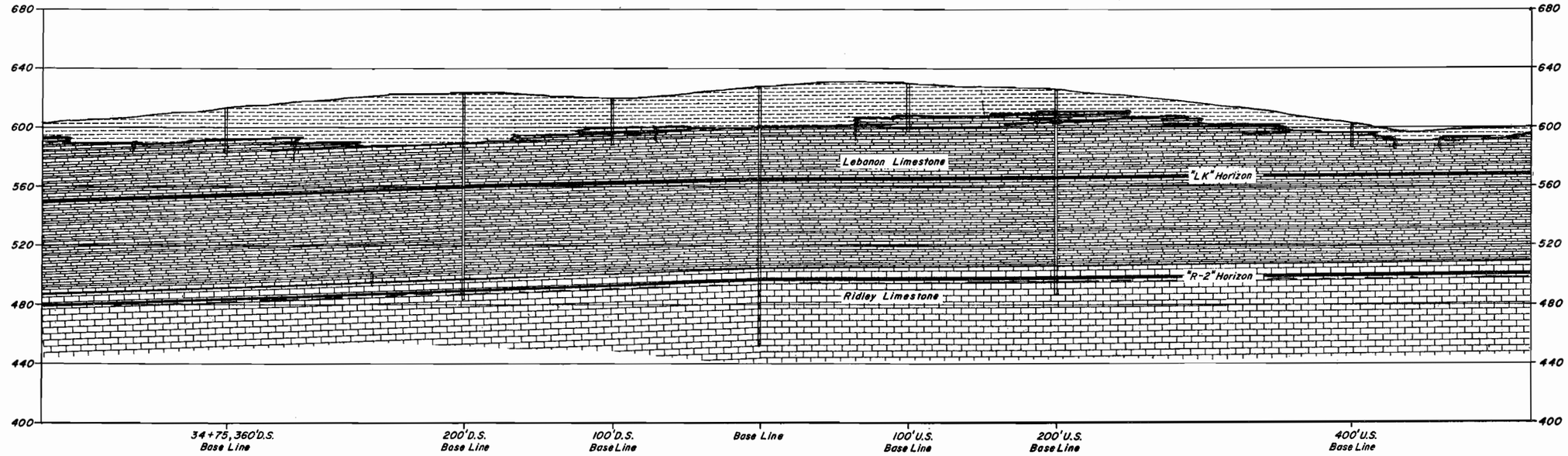
GEOLOGIC SECTIONS BASELINE, 200' U.S. & 200' D.S.

DUCK RIVER PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING

SUBMITTED	RECOMMENDED	APPROVED
R. W. Ash	John M. Kelley	Robert Montgomery

KNOXVILLE	3-10-67	W	GE	1	822 PP1657-2

EXHIBIT 18



NOTES:

1. The Lebanon Limestone is a thinly interbedded limestone and shale containing some partially decomposed shale horizons. "LK" is a correlative horizon only.
2. The Ridley Limestone contains a very persistent weathered and partial cavity horizon approximately 3.0' below "R-2". "R-2" is a correlative horizon only.
3. For drill hole location, see drawing W PP I 461WW124 R-1.

LEGEND:

- 571.2 – Surface elevation.
- T.R. 565.0 – Top of rock elevation.
- F.C., O.C. – Filled or open cavity.
- – Clay on bedding.
- – Possible clay on bedding.
- – Weathered joint.
- – Weathered bedding plane.
- W.L. – Loss of drill water.
- 3/30 – Water test gpm/psi.

SCALES:

40 0 40 80 Feet
Geologic Section

20 0 20 40 Feet
Graphic Logs – Vertical Only

REV NO.	DATE	MADE	CHKD	SUPV	INSP
DRWN		COMPUTED			
TRCD		ENGINEER			
CHKD					

COLUMBIA UNIT
DUCK RIVER-MILE 136.9

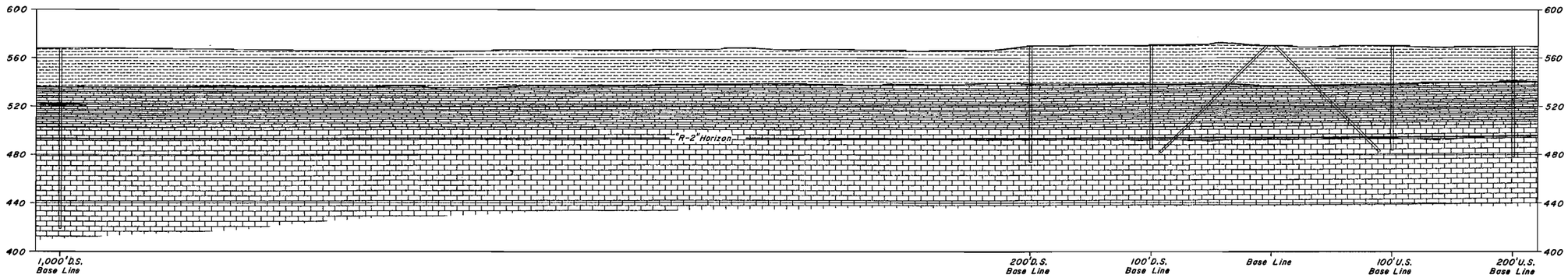
GEOLOGIC SECTION AND GRAPHIC LOGS ALONG STATION 35+00

DUCK RIVER PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING

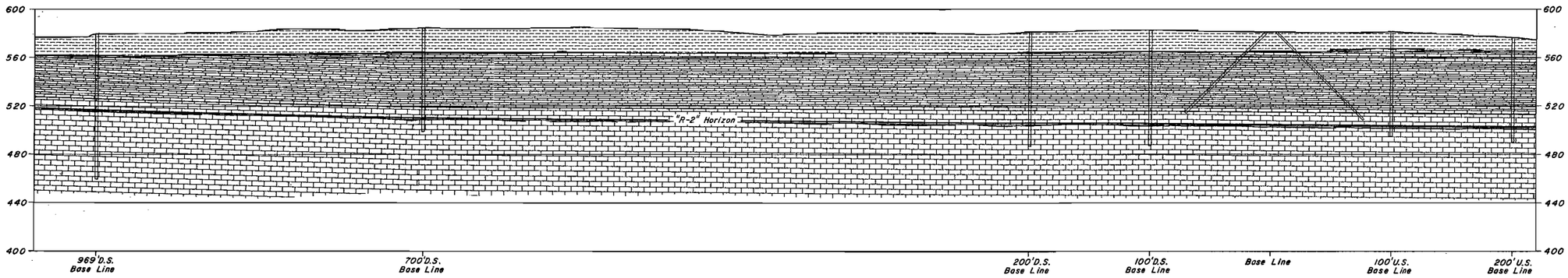
SUBMITTED	RECOMMENDED	APPROVED
R.A. Mc	John M. Killebrew	Reuben E. Morgenthau

KNOXVILLE | 3-28-67 | W | GE | I | 822K1657-5

EXHIBIT 19



Section Along Station 39+00



Section Along Station 47+00

LEGEND:

- Soil
- Lebanon Formation
- Ridley Formation

NOTES:

1. The Lebanon formation contains many, very thin, partially decomposed, shale horizons and a number of gypsum layers from 0.1" to 0.01" thick. Portions of this formation are subject to rapid mechanical decomposition on exposure.
2. The Ridley formation contains a very persistent 0.1' bedding plane cavity at approximately 3.0' below the "R-2" key horizon.
3. For drill hole location, see drawing W PP1 461 WW 124 R-1.
4. For additional sections, see companion drawings.

SCALE:

40 0 40 80 Feet

REV NO.	DATE	MADE	CHKD	SUPV	INSP
DRWN		COMPUTED			
TRCD		ENGINEER			
CHKD					

COLUMBIA UNIT
DUCK RIVER-MILE 136.9

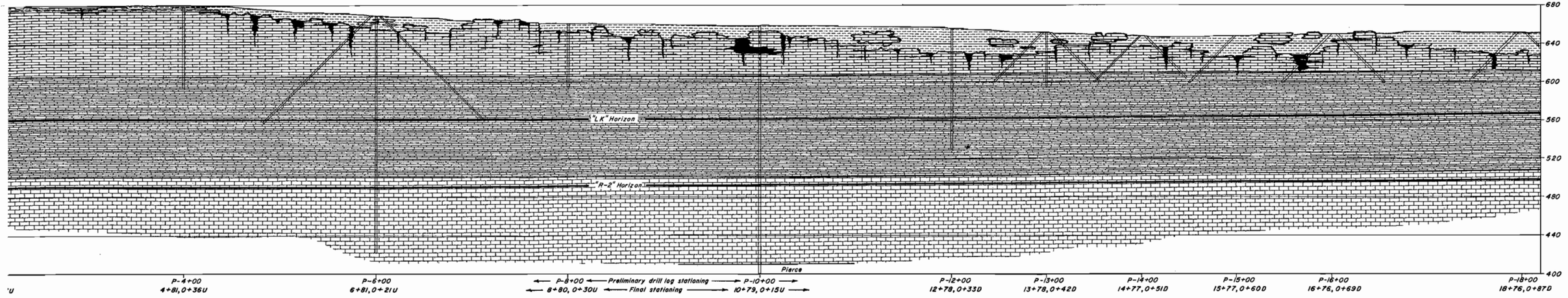
GEOLOGIC SECTIONS ALONG STATIONS 39+00 & 47+00

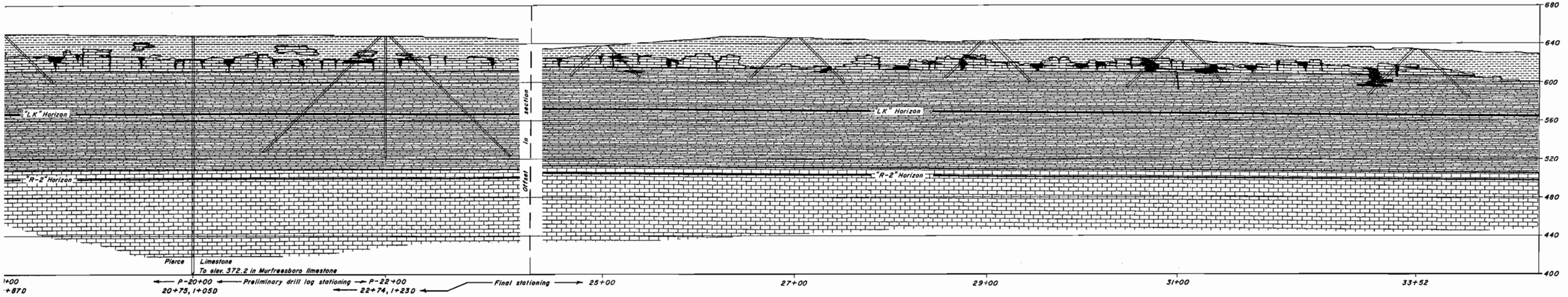
DUCK RIVER PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING

SUBMITTED	RECOMMENDED	APPROVED
R.W. Ada	John M. Kellberg	Andrew L. Mongomery

KNOXVILLE	3-15-67	W	GE	1	822N1657-4

EXHIBIT 20





LEGEND:

- Soil
- Hermitage Formation
- Carters Formation
- Lebanon Formation
- Ridley Formation

NOTES:

1. Very limited weathering was encountered below the Carters formation.
2. Horizons "LK" and "R-2" are for reference only.
3. For additional geologic sections, see companion drawings.
4. For drill hole location, see drawing W PP1 461WW124 R-1.
5. For graphic logs, see drawing series 822 K 1656.

SCALE:

40 0 40 80 120 Feet

COLUMBIA UNIT
DUCK RIVER-MILE 136.9

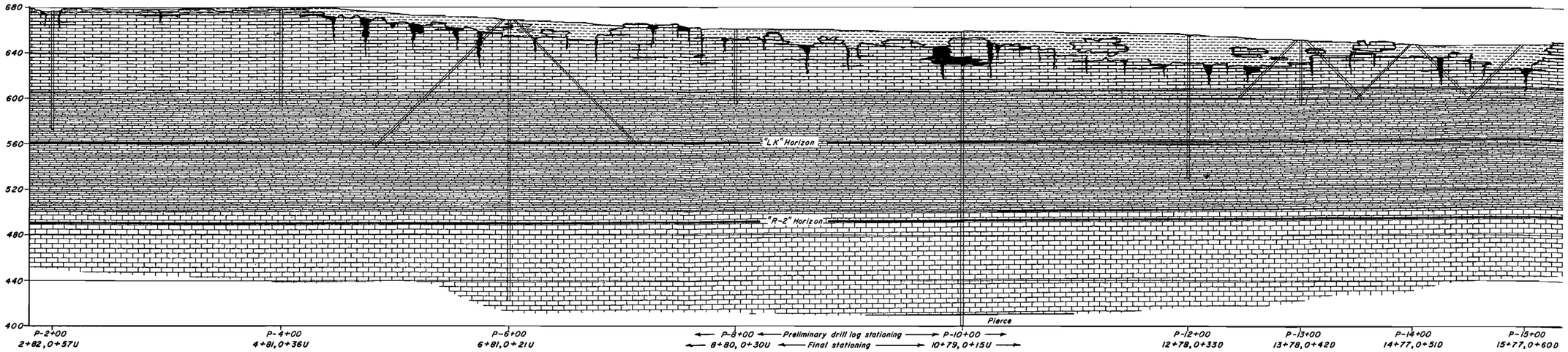
GEOLOGIC SECTION
RIGHT RIM

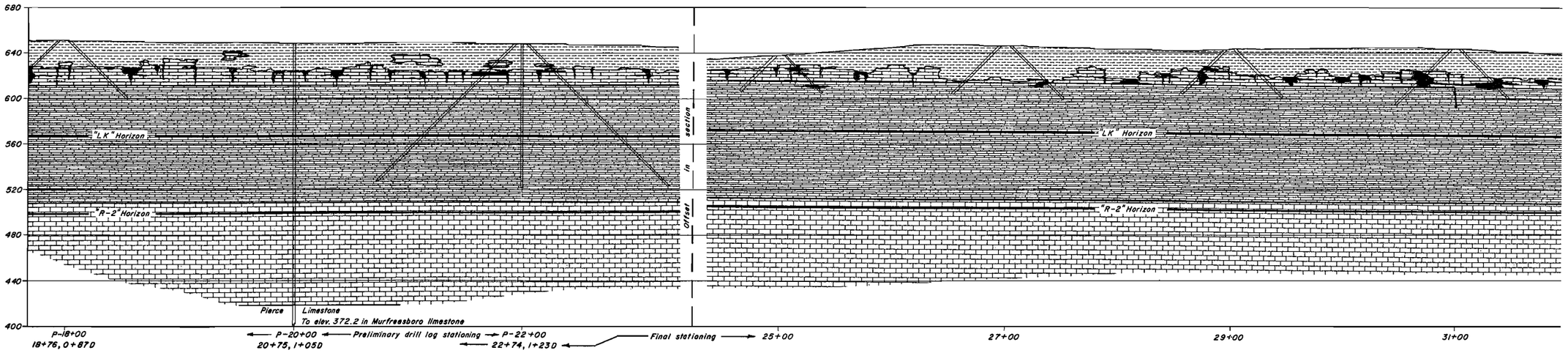
DUCK RIVER PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING

RECOMMENDED	REVIEWED	APPROVED
R.W. Allen	John M. Ruffner	Gordon E. Morgenstern

KNOXVILLE	3-10-67	W	GE	1	822W1657-1

RECORD DRAWING AS CONSTRUCTED





LEGEND:

- Soil
- Hermitage Formation
- Carters Formation
- Lebanon Formation
- Ridley Formation

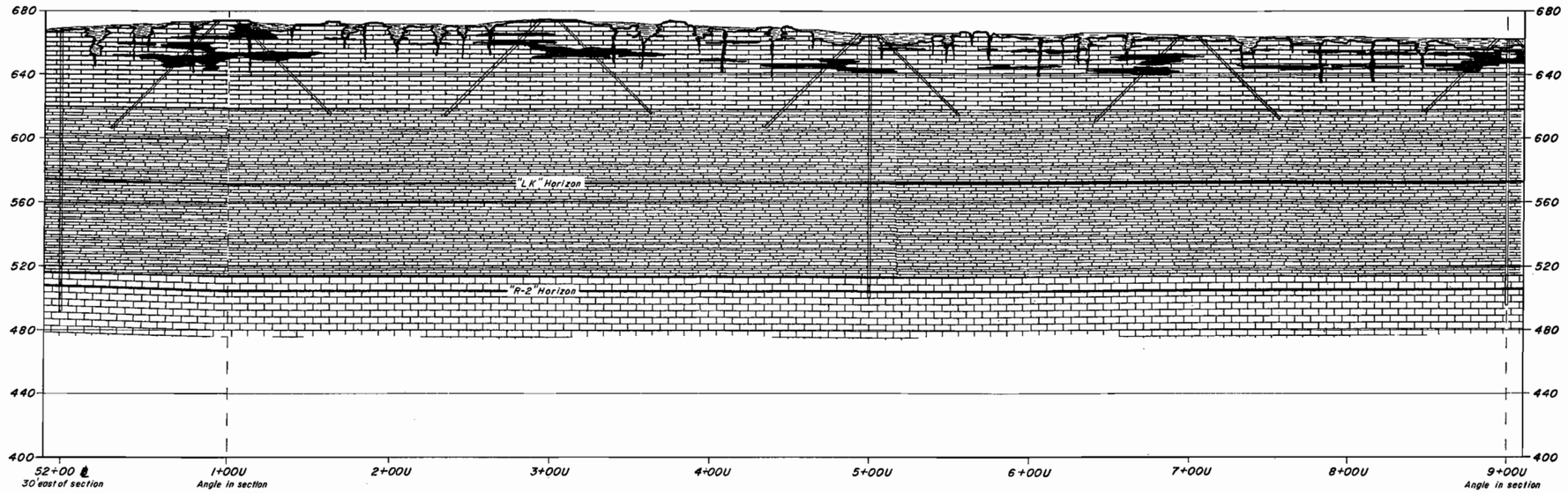
NOTES:

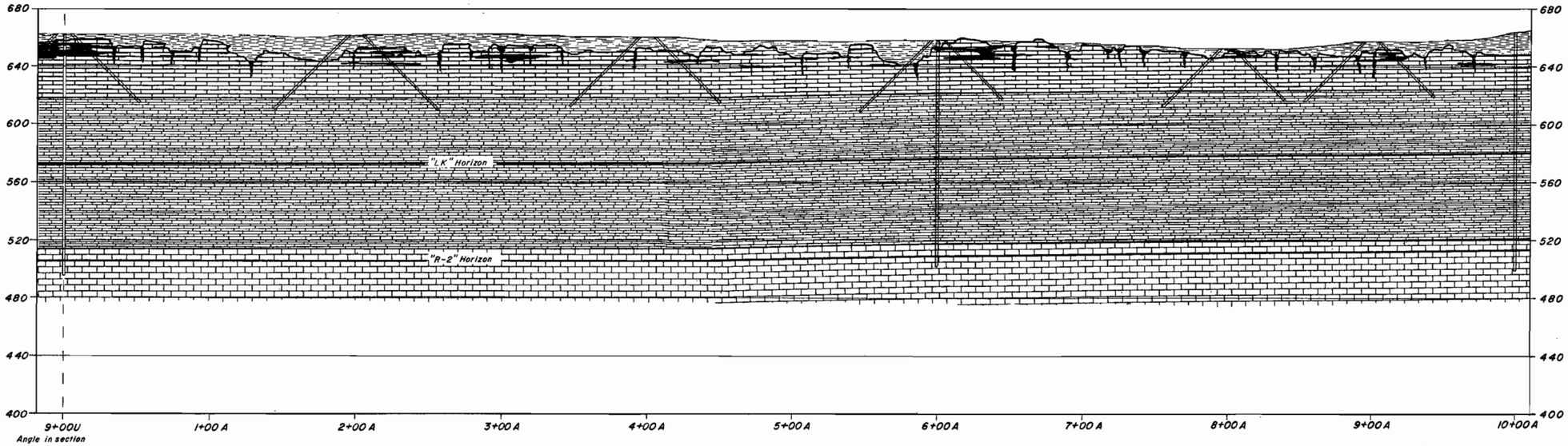
1. Very limited weathering was encountered below the Carters formation.
2. Horizons "LK" and "R-2" are for reference only.
3. For additional geologic sections, see companion drawings.
4. For drill hole location, see drawing W PP1 461WW124 R-1.
5. For graphic logs, see drawing series 822 K 1656.

REV NO.	DATE	MADE	CHKD	SUPV	INSP	SUBM	RECM

DSGN.....
DRWN.....
CHKD.....
TRCD.....
COMP.....
SUPV.....
INSP.....
ENGINEER

EXHIBIT 21





LEGEND:

- Soil
- Carters Formation
- Lebanon Formation
- Ridley Formation

NOTES:

1. No significant weathering was encountered below the Carters formation.
2. Horizons "LK" and "R-2" are for reference only.
3. For additional geologic sections, see companion drawings.
4. For drill hole location, see drawing W PP I 461WW124 R-1.

SCALE: 40 0 40 80 Feet

REV NO.	DATE	MADE	CHKD	SUPV	INSP
DRWN		COMPUTED			
TRCD		ENGINEER			
CHKD					

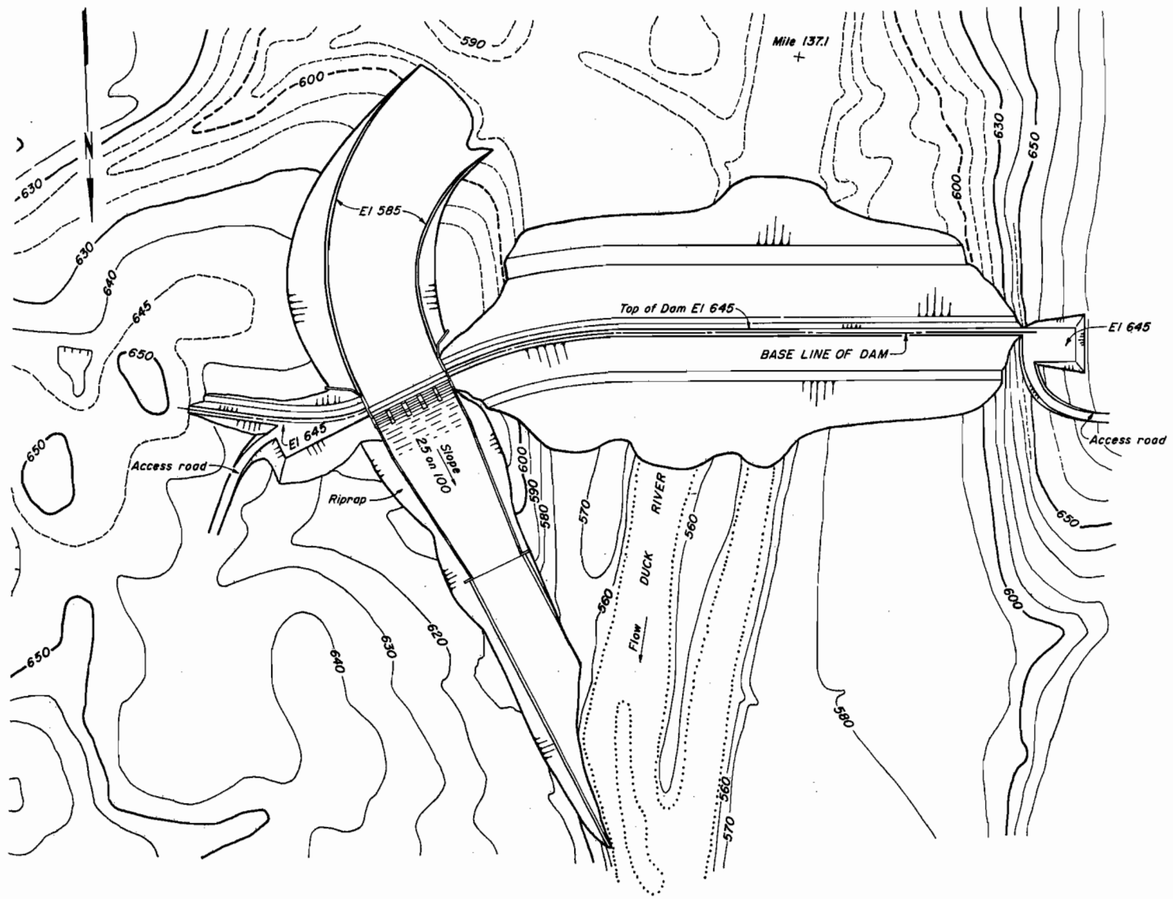
COLUMBIA UNIT
DUCK RIVER - MILE 136.9

GEOLOGIC SECTION
LEFT RIM

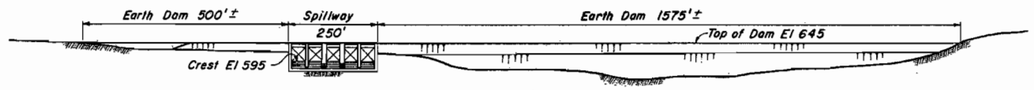
DUCK RIVER PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING

SUBMITTED	RECOMMENDED	APPROVED
R.W. Allen	John M. Kelley	Barbara S. Morgwecki

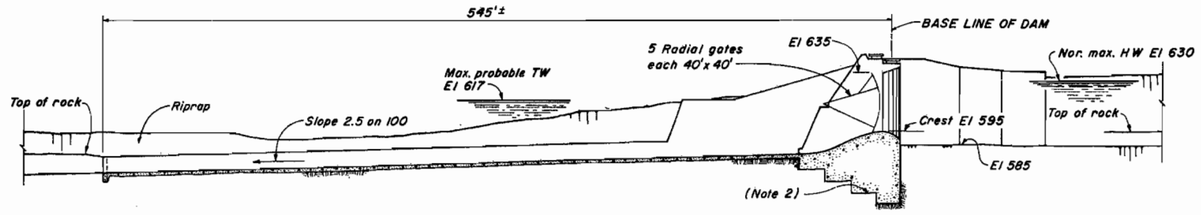
KNOXVILLE	3-10-67	W	G E	I	822K1657-3



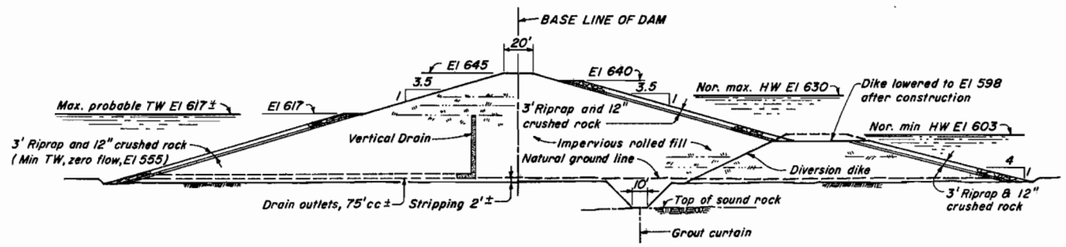
GENERAL PLAN



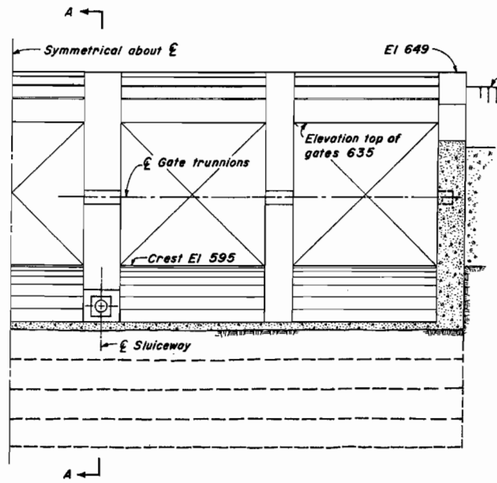
DOWNSTREAM ELEVATION



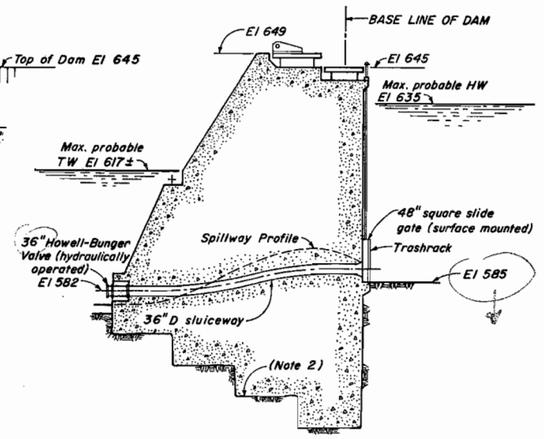
SECTION ALONG ℄ SPILLWAY



TYPICAL SECTION THRU DAM



DOWNSTREAM ELEVATION



SECTION A-A

SPILLWAY
(SHOWING SLUICEWAY THRU PIER)

Scale 200 0 200 400 Feet
GENERAL PLAN & DOWNSTREAM ELEVATION

Scale 50 0 50 100 Feet
SECTION THRU DAM & ALONG ℄ SPILLWAY

Scale 20 0 20 40 Feet
SPILLWAY

NOTES:
1. Topography taken from Keish topography Dwg. No. G-MS-461 P 746-403.
2. Depth of excavation to be determined by foundation conditions.

REV NO.	DATE	MADE	CHKD	SUPV	INSP
1	8-26-68	DJC			
Relocate 36"D sluiceway					

DRWN DBC DJC COMPUTED
TRCD ENGINEER
CHKD

COLUMBIA UNIT
DAM & SPILLWAY

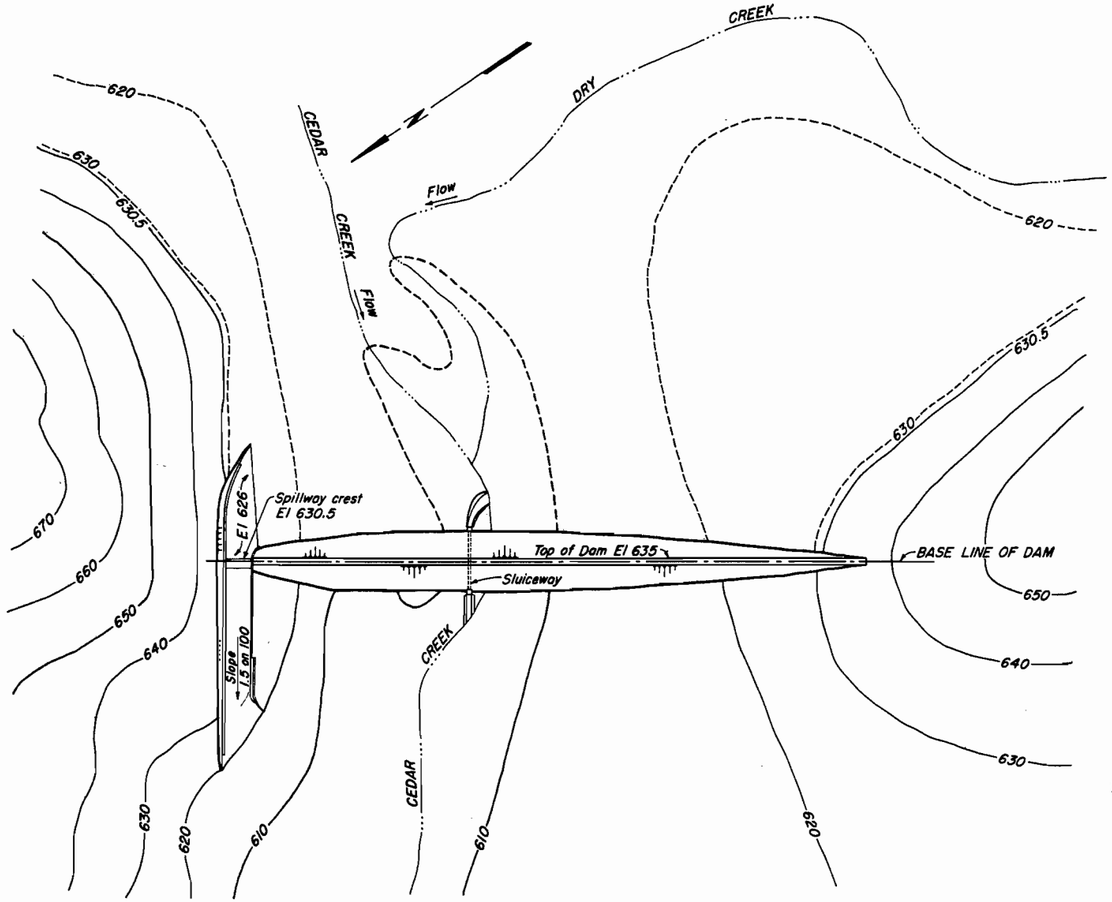
PLAN, ELEVATION AND SECTIONS

DUCK RIVER PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING

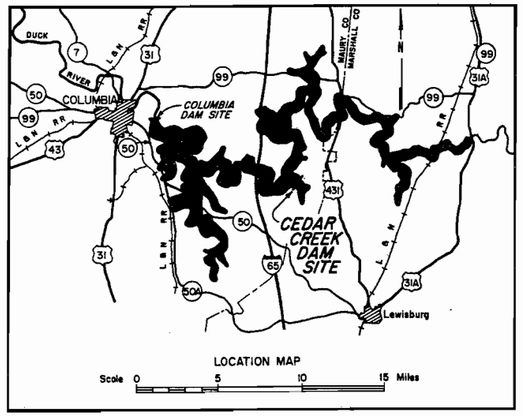
SUBMITTED	RECOMMENDED	APPROVED
J. L. Fergusson	Don H. Matthews	Rudolph Schild

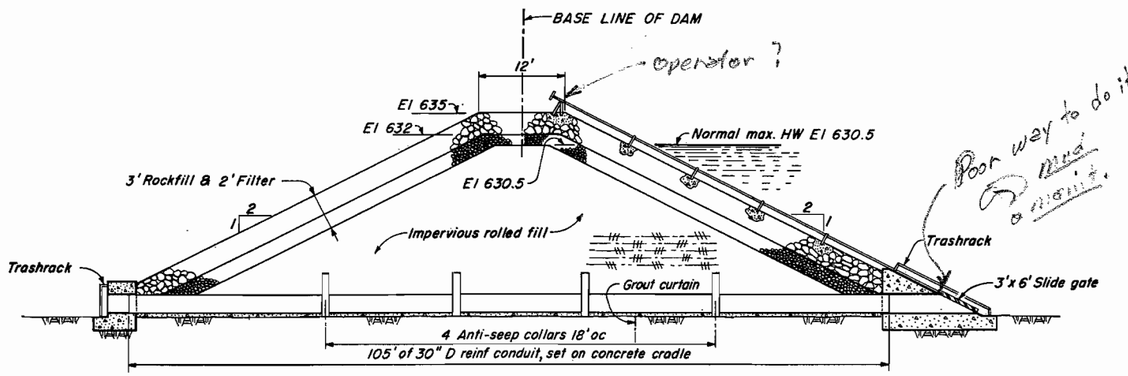
KNOXVILLE	6-22-66	W	PP	1	120K289 R1

EXHIBIT 23

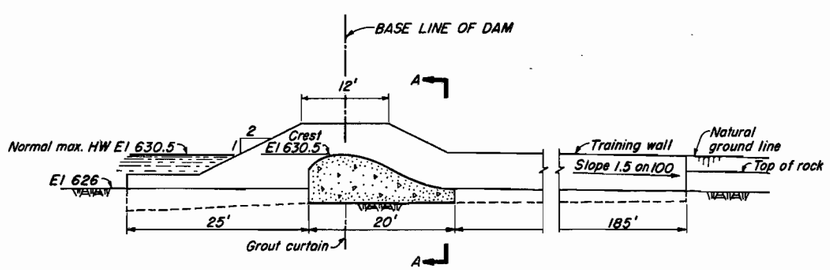


GENERAL PLAN

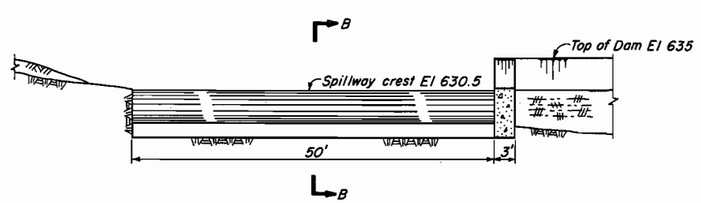




SECTION THRU DAM & SLUICEWAY



SECTION B-B



SECTION A-A

SECTIONS THRU SPILLWAY

Scale 150 0 150 300 Feet
PLAN

Scale 10 0 10 20 Feet
SECTIONS

REV NO.	DATE	MADE	CHKD	SUPV	INSP
DRWN DJC		COMPUTED			
TRCD		ENGINEER			
CHKD		P.E. Cagle			

CEDAR CREEK WATERFOWL REFUGE
DAM & SPILLWAY

PLAN AND SECTIONS

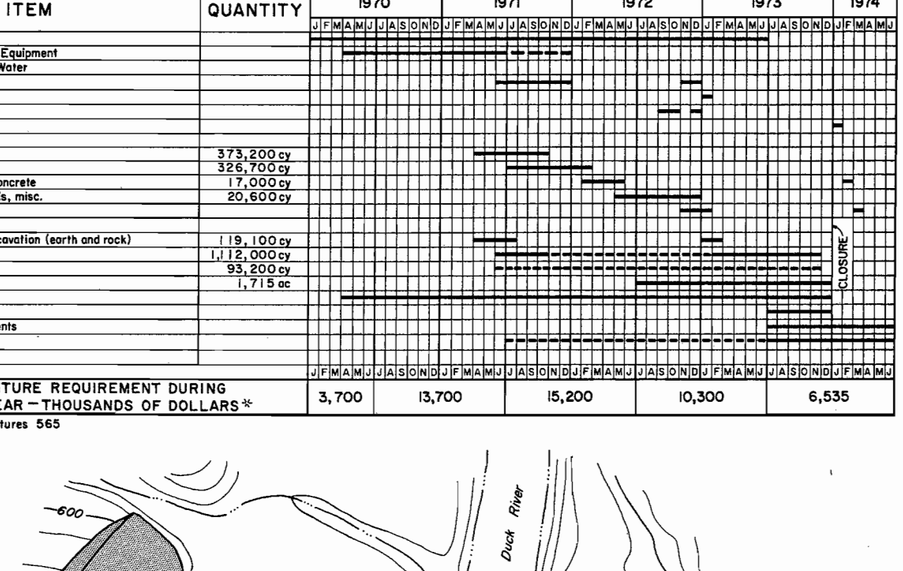
DUCK RIVER PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING

SUBMITTED	RECOMMENDED	APPROVED
J. L. Ferguson	Benj. H. Matteson	Reed A. Elliott

KNOXVILLE	8-16-67	W	PP	1	120 K 290

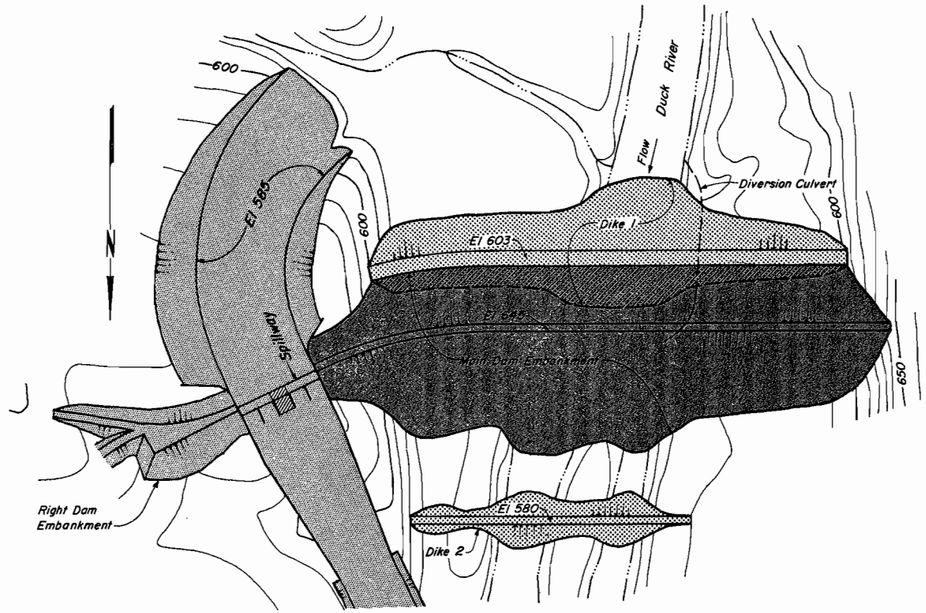
COLUMBIA UNIT
CONSTRUCTION PLANNING SCHEDULE

ITEM	QUANTITY
Land and Acquisition	
Construction Plant and Equipment	
Diversion and Care of Water	
- Dike 1	
- Dike 2	
- Diversion culvert	
- Bulkhead	
Spillway	
- Earth excavation	373,200 cy
- Rock excavation	326,700 cy
- Overflow mass concrete	17,000 cy
- Pier, training walls, misc.	20,600 cy
- Spillway gates	
Earth Fill Dam	
- Stripping and excavation (earth and rock)	119,100 cy
- Earth fill	1,112,000 cy
- Slope protection	93,200 cy
Reservoir Clearing	1,715 ac
Reservoir Adjustments	
Cedar Creek Dam	
General Yard Improvements	
Public Use Facilities	



EXPENDITURE REQUIREMENT DURING FISCAL YEAR — THOUSANDS OF DOLLARS*	3,700	13,700	15,200	10,300	6,535

* Prior Years Expenditures 565



DIVERSION SCHEME

Scale 200 0 200 400 Feet

LEGEND:

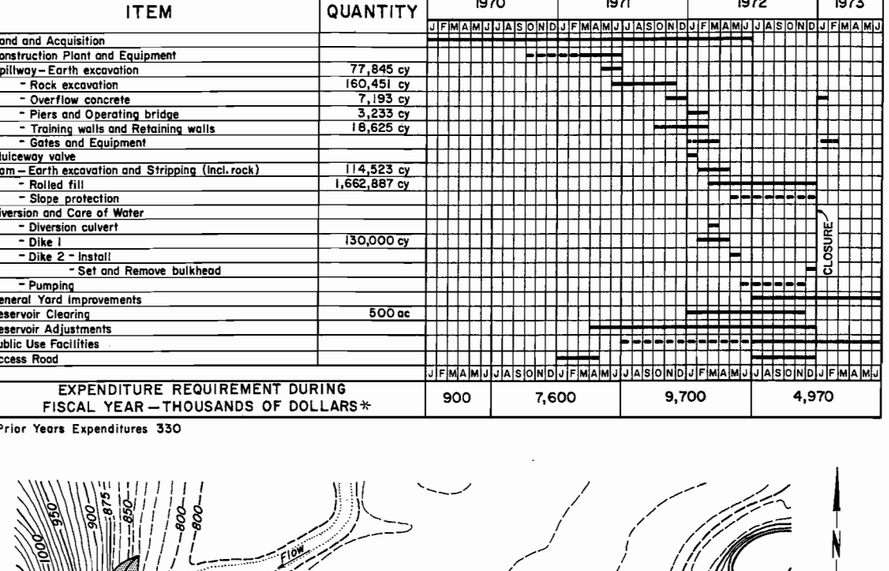
- *First stage construction*
- *Second stage construction*
- *Third stage construction*
- *Closure*

COLUMBIA CONSTRUCTION PROCEDURE:

(River diversion based on 5-year frequency annual flow of 36,000 cfs.)
STAGE 1 (River flow in natural channel)
1. Excavate spillway channels, construct spillway (one bay left at El 585) and right dam embankment and part of dike 1.
2. Place diversion culvert and excavate culvert channels.
STAGE 2 (Diversion thru culvert)
3. Complete dike 1.
4. Plug diversion culvert and place dike 2.
STAGE 3 (Diversion thru spillway)
5. Construct main dam embankment.
CLOSURE (Diversion thru completed bays of spillway and sluiceways)
6. Close off incompleted bay of spillway.
7. Construct spillway weir to El 595.

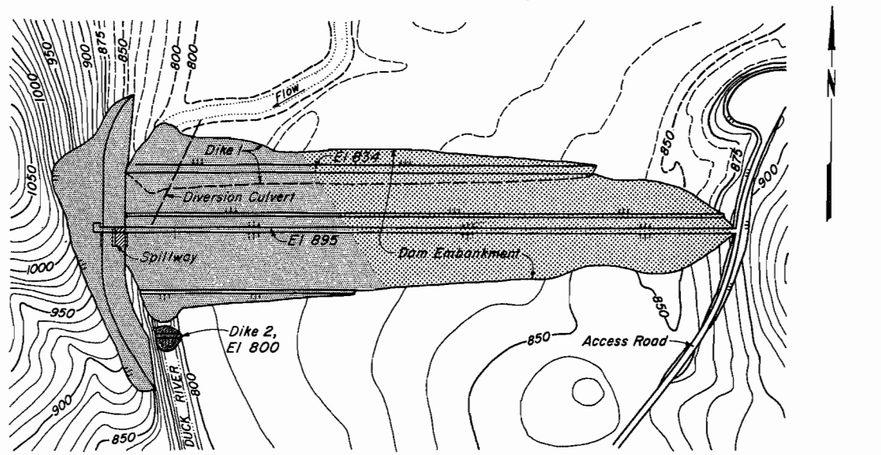
NORMANDY UNIT
CONSTRUCTION PLANNING SCHEDULE

ITEM	QUANTITY
Land and Acquisition	
Construction Plant and Equipment	
Spillway — Earth excavation	77,845 cy
- Rock excavation	160,451 cy
- Overflow concrete	7,193 cy
- Piers and Operating bridge	3,233 cy
- Training walls and Retaining walls	18,625 cy
- Gates and Equipment	
Sluiceway valve	
Dam — Earth excavation and Stripping (incl. rock)	114,523 cy
- Rolled fill	1,662,887 cy
- Slope protection	
Diversion and Care of Water	
- Diversion culvert	
- Dike 1	130,000 cy
- Dike 2 - Install	
- Set and Remove bulkhead	
- Pumping	
General Yard Improvements	
Reservoir Clearing	500 ac
Reservoir Adjustments	
Public Use Facilities	
Access Road	



EXPENDITURE REQUIREMENT DURING FISCAL YEAR — THOUSANDS OF DOLLARS*	900	7,600	9,700	4,970

* Prior Years Expenditures 330



DIVERSION SCHEME

Scale 300 0 300 600 Feet

NORMANDY CONSTRUCTION PROCEDURE:

(River diversion based on 5-year frequency April thru November flood of 4,100 cfs.)
STAGE 1 (River flow in natural channel)
1. Excavate spillway channels and construct spillway. (One bay left at El 830)
2. Place diversion culvert and excavate culvert channels. Begin dike 1 and dam embankment.
STAGE 2 (River flow thru culvert)
3. Complete dike 1 and continue dam embankment.
STAGE 3 (River flow thru spillway)
4. Plug diversion culvert and place dike 2.
5. Complete dam embankment.
CLOSURE (Diversion thru completed bay of spillway and sluiceway)
6. Close off incompleted bay of spillway.
7. Construct spillway weir to El 840.

REV NO.	DATE	MADE	CHKD	SUPV	INSP
DRWN. MTW		COMPUTED			
TRCD.		ENGINEER			
CHKD. DBC					

NORMANDY AND COLUMBIA UNITS

CONSTRUCTION PLANNING SCHEDULE AND DIVERSION SCHEME

DUCK RIVER PROJECT
TENNESSEE VALLEY AUTHORITY
DIVISION OF CONSTRUCTION

SUBMITTED	RECOMMENDED	APPROVED
J. C. Sherrod		

KNOXVILLE | 8-21-68 | W | CP | 1 | 102K1